State of California
The Resources Agency
Department of Water Resources
Environmental Services Office

SUISUN MARSH SALINITY CONTROL GATES ANNUAL FISHERIES MONITORING REPORT FOR 1997

Memorandum Report

November 1999

Copies of this report may be obtained without charge from:

State of California
Department of Water Resources
P.O. Box 942836
Sacramento, CA 94236-0001

If you need this publication in an alternate form,
contact the Environmental Services Office at (916) 227-1375
or the Office of Water Education at (800) 272-8869.

Contents

Figures

Tables

Chapter 1
Introduction

Under US Army Corps of Engineers Permit 16223E58 and San Francisco Bay Conservation and Development Commission Permit 4-84(M), the California Department of Water Resources (DWR) must submit an annual fisheries monitoring report. The objective of the monitoring program is to determine potential effects of Suisun Marsh Salinity Control Gates operation on fish populations and their food sources. Figure 1 shows the location of the Suisun Marsh Salinity Control Gates (SMSCG). The SMSCG are a key feature of the *Plan of Protection for the Suisun Marsh* (DWR 1984). The SMSCG serve to reduce channel salinity in Montezuma Slough and other Suisun Marsh channels during periods of low to moderate Delta outflow to achieve the following:

- Provide brackish water to managed wetlands.
- Meet channel water salinity standards in the marsh prescribed by the State Water Resources Control Board (SWRCB) Water Quality Control Plan 95-6 (as then implemented) and the Suisun Marsh Preservation Agreement (Tables 1 and 2).

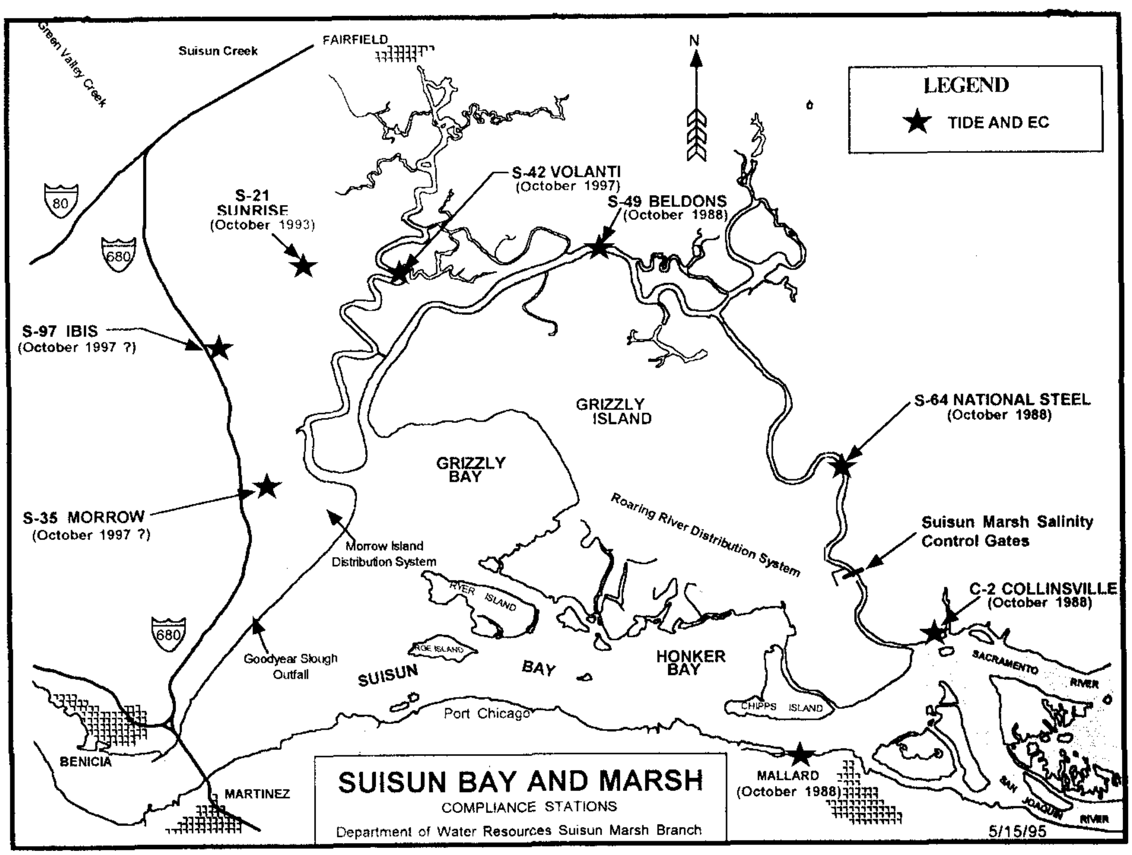

Figure 1 Location of Suisun Marsh Salinity Control Gates and specific conductance monitoring stations

Table 1 Mean monthly specific conductance standards for Suisun Marsh from SWRCB Order WR 95-6

Month	*Eastern Marsh Standards (mS/cm)*	*Western Marsh Standards (mS/cm)*	*Deficiency Period Standards for the Western Marsh (mS/cm)*
October	19.0	19.0	19.0
November	15.5	16.5	16.5
December	15.5	15.5	15.6
January	12.5	12.5	15.6
February	8.0	8.0	15.6
March	8.0	8.0	15.6
April	11.0	11.0	14.0
May	11.0	11.0	12.5

Table 2 Mean monthly specific conductance standards from the Suisun Marsh Preservation Agreement

Month	*Normal Standards (mS/cm)*	*Deficiency Period Standards for the Entire Marsh (mS/cm)*
October	19.0	19.0
November	16.5	16.5
December	15.5	15.6
January	12.5	15.6
February	8.0	15.6
March	8.0	15.6
April	11.0	14.0
May	11.0	12.5

These standards serve to maintain the historical brackish water environment of the marsh and ensure germination and growth of important waterfowl food plants. This report summarizes the various elements of the fisheries monitoring program for the 1997 control season, October 1996 through May 1997. Relevant information from prior years is incorporated into much of the analysis. Results from monitoring before 1987 and details of the sampling programs are described in the *Pre-Project Fishery Resource Evaluation* (Spaar 1988).

Chapter 2

Suisun Marsh Salinity Control Gate Operations from 1988 through 1997

The primary objective of the SMSCG are to help meet State Water Resources Control Board channel water salinity standards by tidally pumping less saline water from the Sacramento-San Joaquin Delta (Delta) through the eastern end of Montezuma Slough into central Suisun Marsh. The timing and magnitude of the response to gate operations vary depending on the distance from the SMSCG and have been discussed in past reports (DWR 1997a).

The SMSCG were operated for a 14-day period in November 1996, after which gate operations ceased and the flashboards were installed and in place until February 1997. No SMSCG operation occurred for the rest of the control season[1]. During the 1997 water year, SMSCG operation was generally not needed because high flows kept specific conductance well below water quality standards. Monthly, high-tide, progressive daily mean specific conductance in Suisun Marsh ranged from 0.09 mS/cm at C-2 in January 1997 to 15.43 mS/cm at
S-35 in October 1996 (Figure 2; based on data from C-2, S-64, S-49, S-21, S-97, and S-35). As usual, there was a general trend of increasing salinity from East to West. Throughout the control season, specific conductance was lowest at C-2, the easternmost station. It was highest at S-35 or S-97, the westernmost stations. The greatest differences in specific conductance between stations occurred in October and November, when monthly average specific conductance differed by as much as 8.72 mS/cm. From January through March, differences between specific conductance were smallest; values ranged from 1.91 to 2.71 mS/cm.

For information on control gate operations between 1988 through 1997, see Table 3 in this report. For more details, see *Suisun Marsh Salinity Control Gates Fisheries Monitoring 1995 Annual Report* (DWR 1997a).

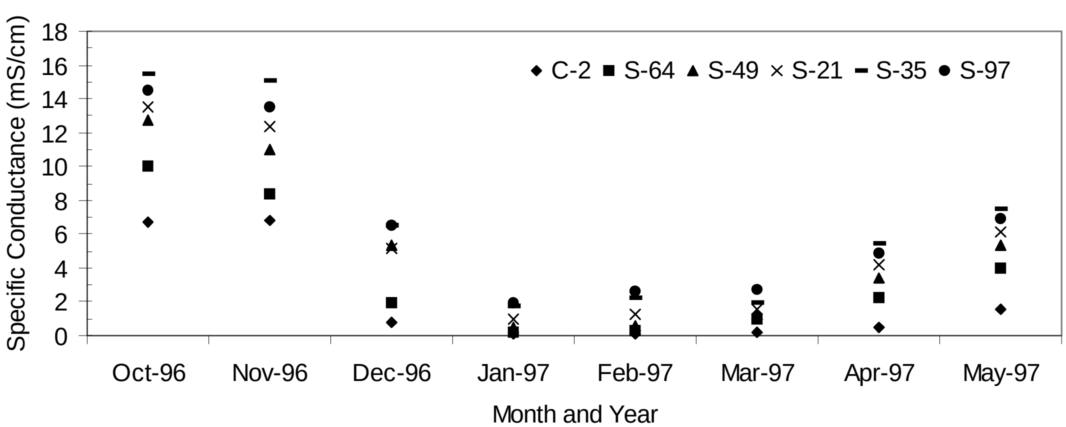

Figure 2 Monthly average specific conductance at various Suisun Marsh stations in water year 1997

1. A control season is defined as 1 October through 30 September of the following calendar year.

Table 3 Suisun Marsh Salinity Control Gates schedule from 1988 through 1997

From	*To*	*Flashboards*	*Gate 1* [a]	*Gate 2* [a]	*Gate 3* [a]	*Remarks*
11/01/88	04/07/89	IN	OP	OP	OP	Full Bore
04/07/89	09/26/89	OUT	O	O	O	Held Open
09/26/89	12/08/89	IN	OP	OP	OP	Full Bore
12/08/89	12/15/89	IN	O	O	O	Open for Test 5
12/17/89	12/22/89	IN	C	C	C	Closed for Test 5
12/22/89	05/31/90	IN	OP	OP	OP	Full Bore
05/31/90	07/15/90	OUT	O	O	O	Held Open
07/16/90	09/27/90	OUT	OP	OP	OP	Gate Test 1
09/28/90	09/30/90	IN	OP	OP	OP	Full Bore
10/01/90	10/30/90	IN	OP	OP	OP	Daylight Only
10/30/90	11/16/90	IN	C	C	C	Middle Gate Broken
11/16/90	11/20/90	IN	OP	C	OP	Middle Gate Broken
11/20/90	11/28/90	IN	OP	OP	OP	Full Bore
11/28/90	12/05/90	OUT	OP	OP	OP	Barge Passing
12/05/90	12/10/90	IN	OP	OP	OP	Full Bore
12/11/90	12/24/90	IN	O	O	O	Rock Slough Standard
12/25/90	05/30/91	IN	OP	OP	OP	Full Bore
05/31/91	07/17/91	OUT	O	O	O	Held Open
07/18/91	09/16/91	OUT	OP	OP	OP	Gate Test 2
09/16/91	10/18/91	OUT	C	C	C	Maintenance
10/18/91	12/11/91	IN	OP	OP	OP	Full Bore
12/12/91	01/09/92	IN	OP	OP	OP	Daylight for Salmon
01/09/92	03/01/92	IN	OP	OP	OP	Full Bore
03/01/92	03/24/92	IN	C	C	C	Winter-run Salmon
03/24/92	05/27/92	IN	OP	OP	OP	Full Bore
05/27/92	10/01/92	OUT	O	O	O	Held Open
10/01/92	10/05/92	IN	OP	OP	OP	One-third Open
10/06/92	10/08/92	IN	OP	OP	OP	Two-thirds Open
10/09/92	10/14/92	IN	O	O	O	Held Open
10/15/92	10/18/92	IN	OP	OP	OP	One-third Open
10/19/92	10/26/92	IN	OP	OP	OP	Two-thirds Open
10/27/92	10/27/92	IN	OP	OP	OP	One-third Open
10/28/92	10/31/92	IN	OP	OP	OP	Manual - AVM Broken
11/01/92	11/02/92	IN	OP	OP	OP	One-third Open

[a] C = Closed, O = Open, OP = Operating.

Table 3 (Continued) Suisun Marsh Salinity Control Gates schedule from 1988 through 1997

From	*To*	*Flashboards*	*Gate 1* [a]	*Gate 2* [a]	*Gate 3* [a]	*Remarks*
11/03/92	11/08/92	IN	OP	OP	OP	Full Bore
11/09/92	01/04/93	IN	OP	OP	OP	One-third Open
01/05/93	01/21/93	IN	OP	OP	OP	Full Bore
01/22/93	05/30/93	IN	O	O	O	Salinity Below Standards
05/31/93	09/06/93	OUT	O	O	O	
09/07/93	09/16/93	IN	O	O	O	
09/17/93	12/13/93	IN	OP	OP	OP	Full Bore
12/13/93	12/14/93	IN	O	O	O	3 Gates Held Open
12/14/93	02/10/94	IN	OP	OP	OP	Full Bore
02/10/94	02/16/94	IN	C	OP	OP	Full Bore, 1 Gate Under Repair
02/16/94	02/18/94	IN	C	C	C	3 Gates Closed
02/18/94	05/09/94	IN	C	OP	OP	Full Bore, 1 Gate Under Repair
05/09/94	05/11/94	OUT	C	OP	OP	Full Bore, 1 Gate Under Repair
05/11/94	08/02/94	OUT	C	O	O	2 Gates Open, 1 Closed
08/02/94	09/01/94	OUT	O	O	O	3 Gates Open
09/01/94	09/03/94	IN	C	C	C	3 Gates Closed
09/03/94	09/06/94	IN	OP	OP	OP	Full Bore
09/06/94	09/08/94	IN	C	OP	OP	2 Gates in Operation
09/08/94	09/09/94	IN	C	C	C	3 Gates Closed
09/09/94	10/07/94	IN	OP	OP	OP	Full Bore Operation
10/08/94	10/23/94	IN	O	O	O	Fish Study, Flashboards Installed
10/24/94	11/14/94	OUT	O	O	O	Fish Study, Without Flashboards
11/15/94	11/17/94	IN	OP	OP	OP	Manual Full Bore Operation
11/18/94	01/10/95	IN	OP	OP	OP	Automatic Full Bore Operation
01/11/95	02/07/95	IN	O	O	O	High Delta Outflow, Below Standards
02/08/95	11/12/96	OUT	O	O	O	High Delta Outflow, Below Standards
11/13/96	11/27/96	IN	OP	OP	OP	Operate Due to Increased Salinity
11/28/96	02/02/97	IN	O	O	O	3 Gates Open, Well Below Standards
02/03/97	10/13/97	OUT	O	O	O	3 Gates Open, Well Below Standards
10/14/97	12/03/97	IN	OP	OP	OP	Operate Due to Increased Salinity
12/04/97	12/31/97	IN	O	O	O	3 Gates Open, Well Below Standards

[a] C = Closed, O = Open, OP = Operating.

Chapter 3
Neomysis and Chlorophyll *a* Sampling

Since 1972, the California Department of Fish and Game (DFG) has conducted field sampling for zooplankton and *Neomysis mercedis* in Suisun Marsh. In 1976, DFG began taking chlorophyll *a* samples as well. This section discusses the abundance of *N. mercedis* and concentration of chlorophyll *a*, an indicator of phytoplankton abundance, over time. *Neomysis mercedis* is a euryhaline zooplankton species that has peak abundance in the entrapment zone (Obrebski and others 1992). Although it has broad salinity tolerance, field studies indicate *N. mercedis* abundance decreases at total dissolved solid levels above 7.2 ppt (11.3 mS/cm) and is extremely low when salinity exceeds 18 ppt (Heubach 1969). Phytoplankton is the primary food source for *N. mercedis*, which, in turn, is an important dietary component for many marsh fishes. Phytoplankton abundance can change quickly, which may affect the abundance of *N. mercedis* and, indirectly, that of many fish species.

Historically, three sites (stations 32, 33, and 34) were sampled in Montezuma Slough and one (S-42) in Suisun Slough (Figure 3). *Neomysis* sampling at station 33 was discontinued in 1977, and station 34 was discontinued in 1984. Please note that these stations should not be confused with the California Department of Water Resources (DWR) Suisun Bay and Marsh Compliance Stations that have similar names. Since 1984, only stations 32 and 42 have been sampled. The site on Montezuma Slough is about 15 miles downstream of the SMSCG, at the western end of the slough. Until 1996, *N. mercedis* and phytoplankton sampling occurred twice monthly from March through October. Normally there was no sampling from November through March due to naturally low winter abundance of *N. mercedis*. However, in water years 1996 and 1997, *N. mercedis* and chlorophyll *a* sampling were conducted monthly throughout the year.

At each site, one *N. mercedis* sample, two zooplankton samples, and one chlorophyll *a* sample are taken. Since 1994, numbers of *Acanthomysis bowmani*, a mysid species that has recently invaded from Asia, have also been enumerated. Surface temperature, water clarity (Secchi depth), and specific conductance are also measured. *Neomysis mercedis*, *A. bowmani*, and larger zooplankton are sampled using a bottom-to-surface oblique tow through the water column with nets attached to a tow frame. Tows last ten minutes. The *N. mercedis* net used since 1974 has a mesh size of 0.505 mm, a mouth diameter of 30 cm, and a length of 1.48 m. The zooplankton net, which is mounted above the *N. mercedis* net, is made of No. 10 nylon mesh, has a mouth diameter of 10 cm, and a length of 73 cm. To sample for microzooplankton, a hose is raised from the bottom to the surface of the water column. At the same time, water is pumped through the hose into a carboy. Subsamples are taken from the water in the carboy. Water for chlorophyll *a* samples is taken from a depth of one meter.

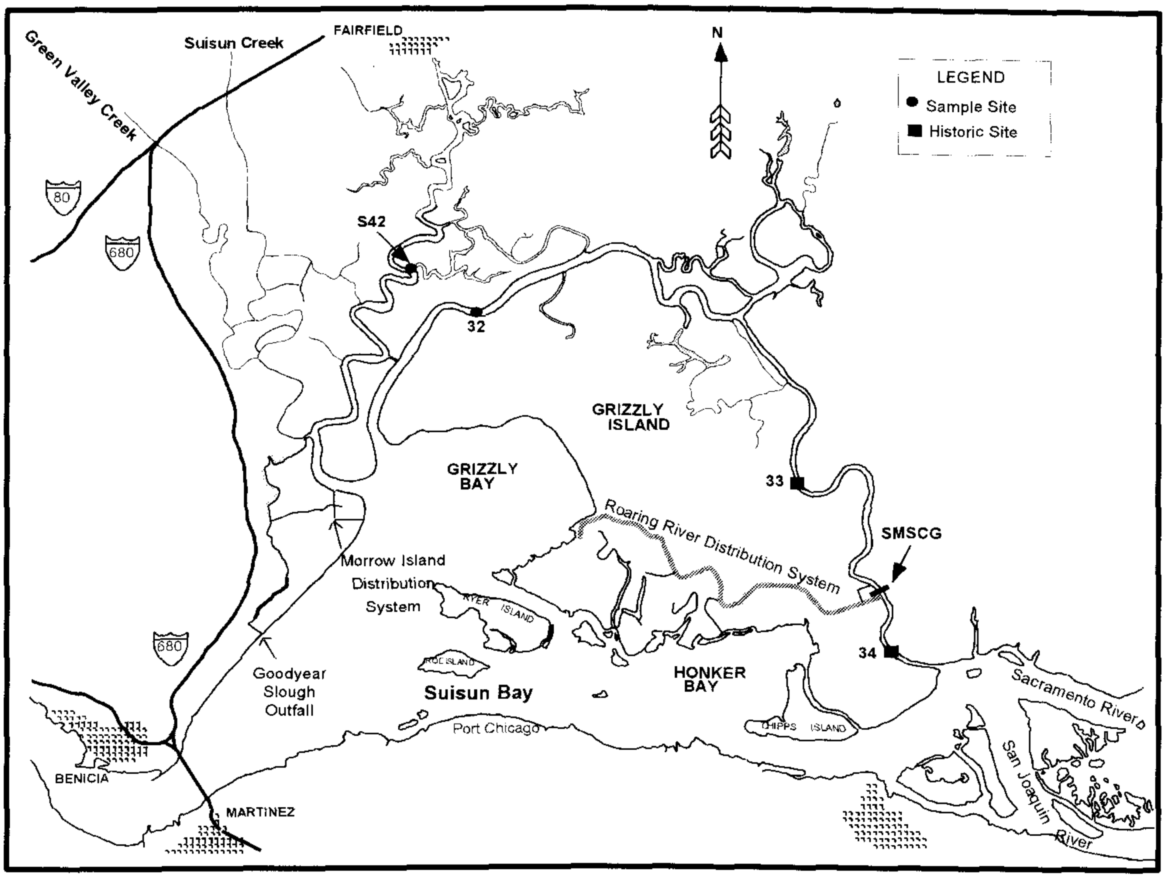

Figure 3 Sampling sites for the *Neomysis*, zooplankton, and chlorophyll *a* survey in Montezuma and Suisun sloughs

Chlorophyll *a* Concentration

Overall, chlorophyll *a* concentration has decreased in Suisun Marsh since 1987 (Figures 4 and 5). During drought years, this decline has been attributed partly to decreases in freshwater flows (Monroe and Kelly 1992). However, the primary factor affecting chlorophyll *a* concentration in recent years in the San Francisco Bay-Delta has been the presence of the suspension-feeding clam *Potamocorbula amurensis*, which invaded this area in 1986 and has since become abundant (Alpine and Cloern 1992; Herbold and others 1992). Alpine and Cloern (1992) determined that mean estimated primary production between 1977 and 1990 decreased from 106 to 39 g C/m/yr in the deep channel and adjacent shallows of the Bay-Delta, presumably due to the intensive grazing pressure by the clam in this region.

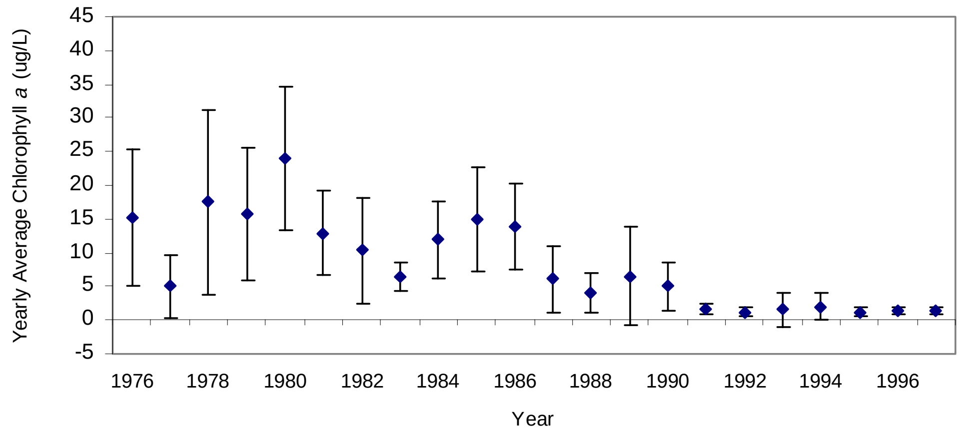

Figure 4 Yearly average chlorophyll *a* and standard deviation values at Station 32 on Suisun Slough from 1976 to 1997

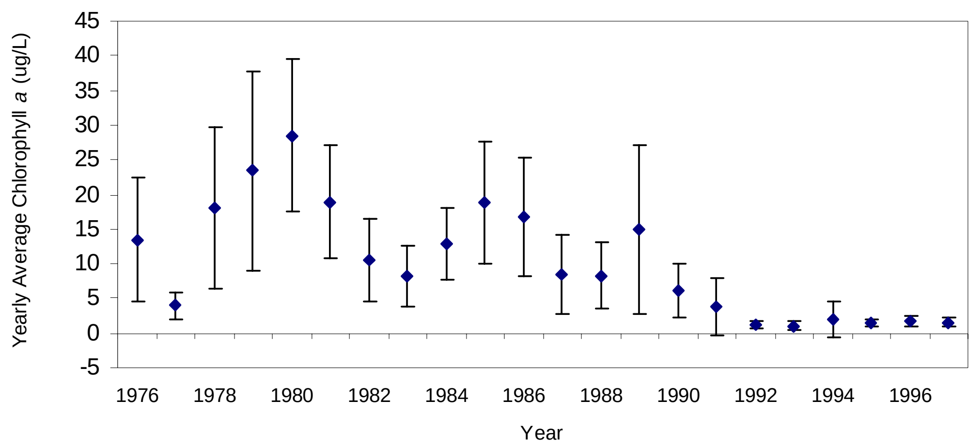

Figure 5 Yearly average chlorophyll *a* and standard deviation values at Station S-42 on Suisun Slough from 1976 to 1997

The University of California, Davis, (UC Davis) Suisun Marsh Fisheries Monitoring reports indicate that *P. amurensis* has been collected in many locations in Suisun Marsh (Matern and others 1995). The clam is reported to be abundant near the downstream mouth of Suisun Slough and has invaded the upstream regions of the slough. In 1994, *P. amurensis* was collected near the SMSCG. In 1996, it was collected at only three western sites in the marsh, while it was collected at five sites in 1997: all four stations on Suisun Slough and one station on Goodyear Slough (Matern and others 1997).

The decrease in chlorophyll *a* concentrations has been apparent in the marsh since 1987, when the clam became abundant and widespread in the bay and estuary. Between 1976 and 1987, 25% of all phytoplankton samples collected in the marsh were at least 20 µg/L, and 43% were less than 10 µg/L. Between 1988 and 1997, approximately 2% of all samples were greater than or equal to 20 µg/L, and 92% of the samples were less than 10 µg/L. The decline appears to have accelerated in recent years: since 1992, 98% of all samples (2 of 128) were <5 µg/L. This ten-year decline in chlorophyll *a* appears most tightly linked to the invasion of *P. amurensis* (Monroe and others 1992).

Construction and operation of the SMSCG do not appear to have further decreased chlorophyll *a* levels. In water year 1989, the year after SMSCG operations began, chlorophyll *a* was higher than in those years immediately preceding gate installation. For example, chlorophyll *a* values in water year 1988 were 1.3 to 15.9 µg/L; in 1989 they were 1.3 to 36.1 µg/L. The peak in 1988 occurred from April to July, with values of 3.7 to 15.9 µg/L in Suisun and Montezuma sloughs. In 1989, the peak occurred later, from June to October, and values in the two sloughs were 4.1 to 36.1 µg/L (above 15 µg/L during five of those months). Whether the 1989 levels were a result of SMSCG operations would be difficult to determine, but these data do suggest that the first year of operation did not decrease phytoplankton production. Further, in 1990 and 1991, chlorophyll *a* concentration ranged from 0.8 to 15.7 µg/L, making it comparable to concentrations in 1987 and 1988 (0.3 to 20.4 µg/L) before SMSCG operation.

Since about 1992, not only has there been a decrease in yearly average chlorophyll *a* concentration, but variability within years (indicated by the standard deviation lines in Figures 4 and 5) has also decreased. This suggests that phytoplankton blooms are either not occurring or are not reaching the peak concentrations once measured in the marsh, presumably due to grazing by *P. amurensis*. There was no phytoplankton bloom in Montezuma Slough in 1992, a critical water year; chlorophyll *a* concentration was less than 2.4 µg/L on all sampling occasions. Concentrations increased somewhat in 1993, peaking at 10 µg/L in May. In 1994 and 1995, chlorophyll *a* concentrations again were low on all sampling occasions. (No samples were taken from January through April 1995.) In 1994, concentrations were 0.3 to 6.8 µg/L. In water year 1995, the highest and lowest chlorophyll *a* concentrations were both measured in December; chlorophyll *a* in Montezuma Slough was 5.2 µg/L and in Suisun Slough it was below the limit of detection. In 1996 and 1997, chlorophyll *a* ranged from 0.5 to about 2.6 µg/L. Herbold and others (1992) suggest that even with an increase in freshwater flows, phytoplankton productivity may continue to be depressed, since *P. amurensis* can tolerate a wide range of salinity.

Neomysis mercedis Abundance

Neomysis mercedis has been declining in Suisun Marsh since the 1970s, with the most dramatic decreases evident after 1991 (Figures 6 and 7). This decline is evident despite fluctuations within years and a dramatic peak in abundance in June 1996, when >3,570 individuals/m^3 were observed at Station 32. As illustrated in Figures 6 and 7, since approximately 1991, the yearly average abundance of *N. mercedis* has decreased and the variability within years (indicated by the standard deviation lines) has also generally decreased. Between 1972 and 1976, yearly peaks in abundance were generally between 300 to 700 individuals/m^3, but on occasion were >4,000 individuals/m^3. In 1977, a drought year, abundance decreased dramatically to <17 individuals/m^3. Between 1978 and 1988, yearly peak abundance of *N. mercedis* was >400 individuals/m^3 in 7 of 11 years in Montezuma Slough and 9 of 11 years in Suisun Slough.

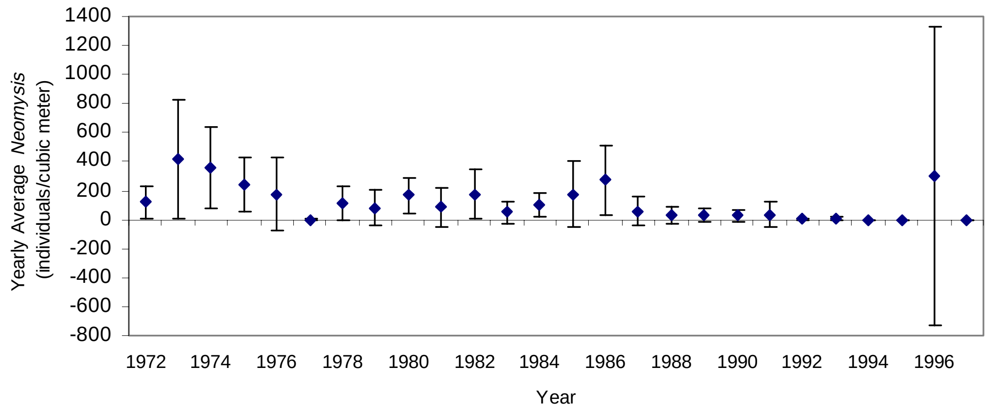

Figure 6 Yearly average *Neomysis mercedis* density and standard deviation values at Station 32 on Montezuma Slough from 1972 to 1997

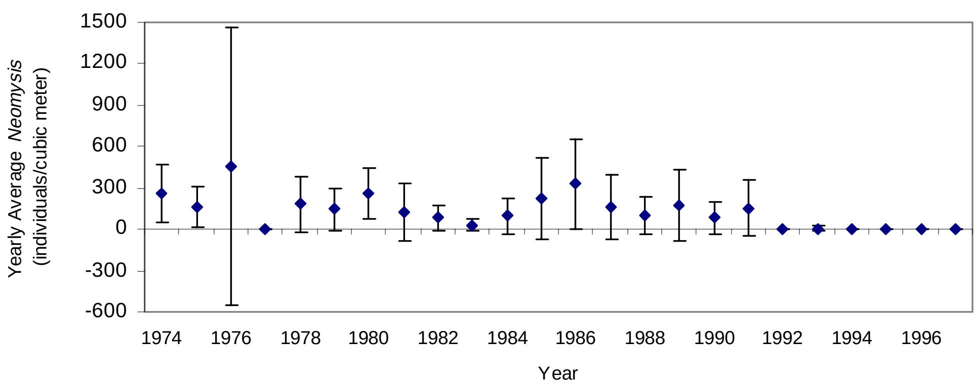

Figure 7 Yearly average *Neomysis mercedis* density and standard deviation values at Station S-42 on Montezuma Slough from 1974 to 1997

Since SMSCG operations began in November 1988, yearly peak *N. mercedis* abundance has ranged from <3 to >3,570 individuals/m^3. In 1991, *N. mercedis* reached levels of 350 individuals/m^3 in Montezuma Slough and 680 individuals/m^3 in Suisun Slough, which was relatively high compared to abundance in the Delta at that time (Spaar 1992). Like chlorophyll *a*, *N. mercedis* decreased significantly in 1992, a critically dry year; peak abundance was <16 individuals/m^3, making it comparable to abundance during the 1977 drought (<17 individuals/m^3). From 1992 to 1995, *N. mercedis* abundance was <60 individuals/m^3 on all sampling dates. In 1993, *N. mercedis* abundance increased slightly from 1992 levels, peaking at 57 individuals/m^3. Yearly peak abundance was low again in 1994, with <4 individuals/m^3. In 1995, abundance was below 1.5 individuals/m^3 on all occasions, except twice in Suisun Slough (4 individuals/m^3 in April and 7 individuals/m^3 in May).

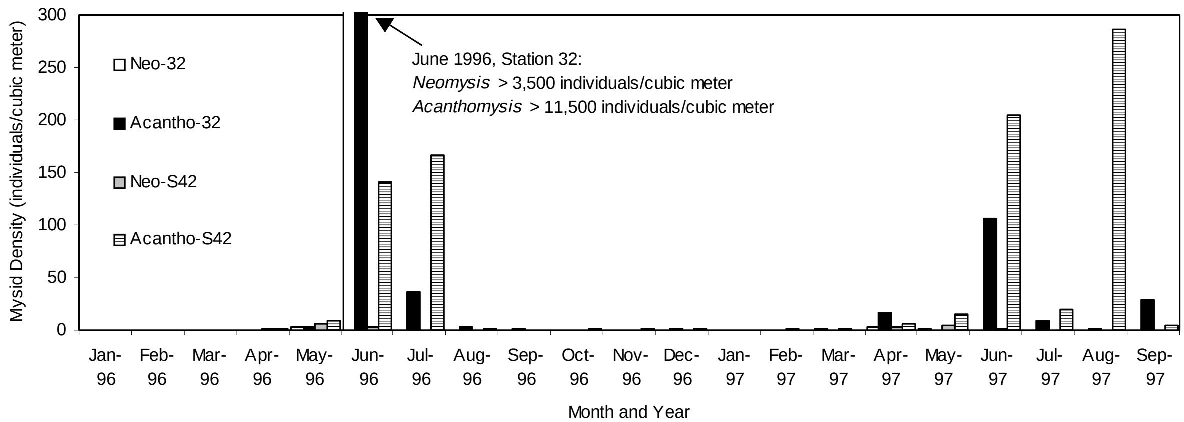

Figure 8 Densities of *Neomysis* and *Acanthomysis* at Stations 32 and S-42 in Suisun Marsh between January 1996 and September 1997

In water year 1996, *N. mercedis* abundance was less than 6 individuals/m^3 until June 1996, when >3,570 individuals/m^3 were counted at Station 32. This is the highest value on record since June 1976 when 4,117 individuals/m^3 were observed at Station S-42. The population crashed the following month (July 1996) and no *N. mercedis* were observed in the water column during sampling until September 1996, when <1 individual/m^3 was observed. It is not known what factors caused this dramatic population increase in June. Historically, *N. mercedis* abundance peaked twice during the year, once in May and June and again in the fall; however, *N. mercedis* now appear to peak only once during the year in June (personal communication with Lee Mecum, unreferenced, see “Notes”). Incidentally, this peak in abundance coincided with a dramatic peak in the abundance of *A. bowmani*, the recently introduced mysid species, which reached 11,544 individuals/m^3 at Station 32 in June (Figure 8). (Abundance of *A. bowmani* was less than 37 individuals/m^3 on all other sampling dates during the 1996 water year.)

Neomysis mercedis densities in water year 1997 were low and ranged from 0 individuals/m^3 in October and November 1996 and August and September 1997, to 4 individuals/m^3 in May 1997. *Acanthomysis bowmani* density peaked during the summer 1997, reaching 286 individuals/m^3 in August (see Figure 8).

The overall decline in *N. mercedis* abundance is consistent with Obrebski and others (1992), who report a decline in the abundance of *N. mercedis* and 12 zooplankton species throughout the Delta in all seasons from 1972 through 1988. They assert that the declines in zooplankton species are not limited to particular regions of the estuary. In Suisun Marsh, the decline is most apparent after 1991 (personal communication with Lee Mecum, unreferenced, see “Notes”). Food limitation, caused by reduced phytoplankton abundance, is the most probable cause for the decline. Orsi and Mecum's (1994) finding of a significant correlation between *Neomysis* abundance and chlorophyll *a* concentration in all seasons from 1968 through 1993 supports this conclusion.

Another factor affecting *N. mercedis* abundance is competition with the recently introduced mysid shrimp, *A. bowmani* (Orsi and Mecum 1994). Orsi (1997) reports that although the introduced mysid was rare during 1992 and 1993, it has been more abundant than *N. mercedis* in the Delta since 1994. Although no studies have yet examined the diet of *A. bowmani*, it is expected to be similar to that of *N. mercedis*. With both species concentrating in Suisun Marsh and the estuarine mixing zone, competition between the species for phytoplankton and zooplankton resources is likely intense (Orsi 1997). Orsi (1997) notes that the decline in *N. mercedis* in 1994, the first year that *A. bowmani* was abundant, suggest that this mysid is out-competing the native *N. mercedis*.

The combined effects of dry and critical water years, low phytoplankton productivity, and invasive species such as *A. bowmani*, have likely led to the low zooplankton abundance in Suisun Marsh. Without the SMSCG, the with-project years from 1989 through 1991 (all dry or critical) might have had extremely low *N. mercedis* density, as in 1977. The SMSCG may have delayed the effect of the drought on *N. mercedis* density until 1992 by reducing April and May salinity and helping to create more favorable conditions for *N. mercedis*. Water Quality Control Plan 95-6 standards for the marsh (11.0 mS/cm from April through May) are slightly high for optimum *N. mercedis* abundance, but SMSCG operations often keep salinity well below these spring levels. Further, operation of the SMSCG can produce a saltwater-freshwater interface in the marsh, similar to the larger channels and bays of the estuary, providing suitable salinity for *N. mercedis*. However, without corresponding increases in chlorophyll *a* or decreases in the abundance of *A. bowmani*, *N. mercedis* will be unable to benefit from this habitat.

Chapter 4
Striped Bass Monitoring

The California Department of Fish and Game's striped bass monitoring consists of two successive survey programs, the Striped Bass Egg and Larva Survey and the Striped Bass Tow-Net survey. The egg and larval survey provides an abundance index of developing striped bass through the spawning season. The tow-net survey provides an index of young-of-the-year striped bass abundance. This section describes results from these surveys.

Striped Bass Egg and Larva Survey

Striped bass spawning is triggered by water temperature, so egg and larval survey dates vary from year to year between February and July. In years before 1991, the survey was initiated early enough to collect eggs and larvae from early striped bass spawning. In 1991, sampling was done weekly from February through mid-July to encompass the delta smelt spawning period. Beginning in 1992 at Suisun Marsh and Suisun Bay sites, sampling was conducted every four days. In 1995, sampling frequency was decreased to every eight days at these sites. To collect the samples, ten-minute oblique tows were made at each station. The net used to collect the samples is 3.18 meters long and is made of 500-micron mesh. Until 1995, sampling occurred throughout Suisun Marsh, Suisun Bay, the Sacramento-San Joaquin Delta, and the Sacramento River. In 1995, several sampling stations were eliminated. Figure 9 shows past and present sampling stations through 1995. Data from 1994 are reported for the first time. Sampling in Suisun Marsh was not conducted after 1995.

In comparison to the Total Delta Index, the Montezuma Slough Index comprises a small proportion of total 6-to-14-mm larval abundance estimated by the survey. However, any area suitable for rearing larval striped bass is important to the estuary's low population. In 1993, the striped bass egg and larva survey was conducted throughout the Delta, including stations in Montezuma Slough for the first time since 1988. Abundance indices since 1984 are shown in Table 4. Larvae collected in 1995 were not measured and consequently, biologists were not able to calculate abundance indices for 6-to-14-mm striped bass.

A 1987 DFG study concluded that the SMSCG would have a minimal effect on striped bass eggs and 3-to-6-mm larvae (Raquel 1988). At the station farthest upstream from the SMSCG, eggs were found on only one sampling run. At the downstream station, no 3-to-6-mm larvae were found. These results suggest that spawning occurs well upstream of the mouth of Montezuma Slough. Based on the limited data available, it appears that the gates are not affecting striped bass egg and larval development. During pre-project years, 6-to-14-mm eggs and larvae in Montezuma Slough comprised 0.04% to 0.20% of the total eggs and larvae in the Delta. In 1993, abundance in Montezuma Slough comprised 2.00% of total egg and larval abundance in the Delta. This is likely because 1993 was an above-normal water year, and the larvae were washed downstream by high flows. In 1994, abundance in Montezuma Slough was 0.28% of total egg and larval abundance in the Delta. This was similar to levels observed in pre-project years.

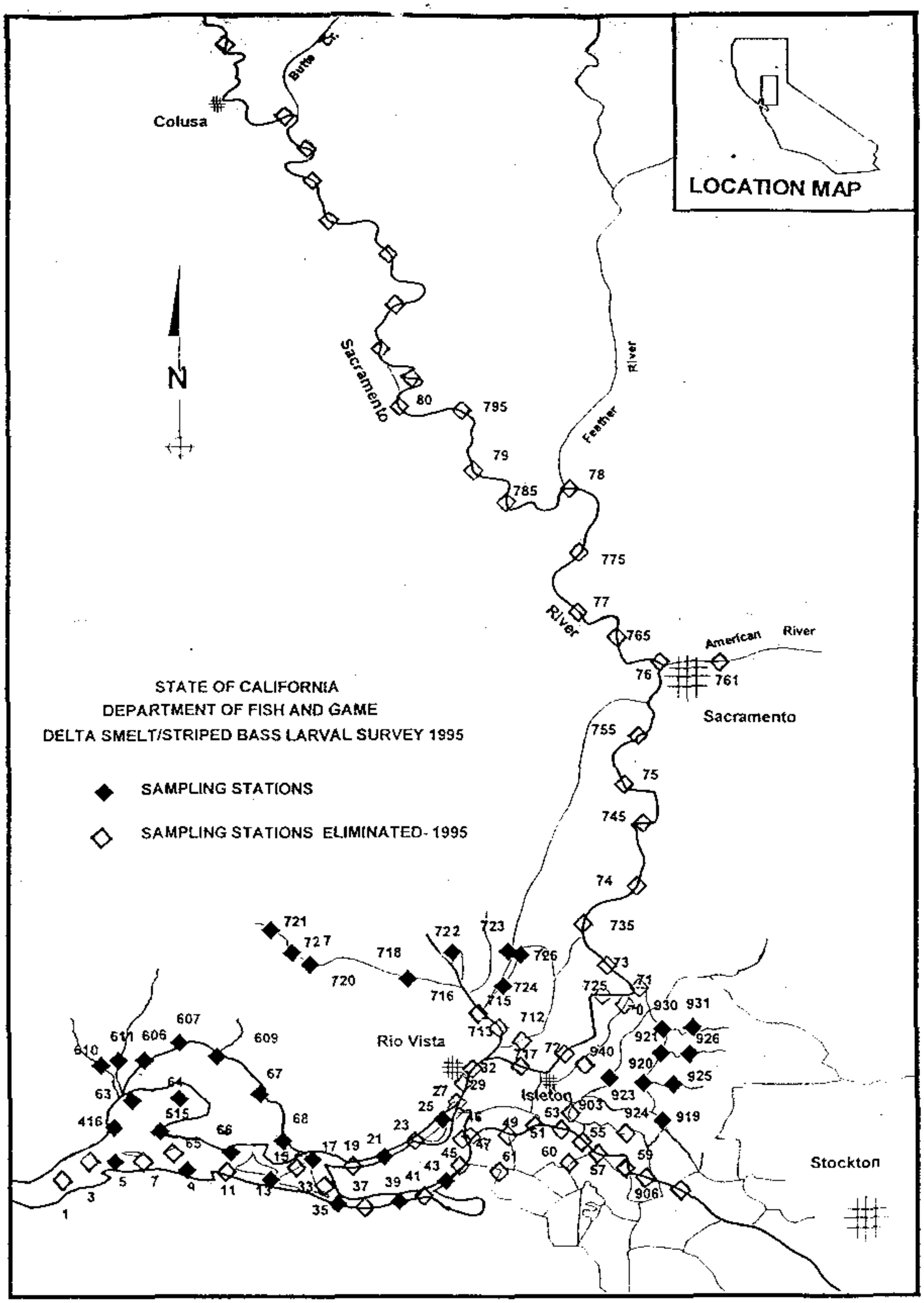

Figure 9 Delta smelt and striped bass larva survey sampling stations

Table 4 Six-to-fourteen-millimeter striped bass abundance indices (abundance x 10,000)

Year	*Total Index*	*Montezuma Slough*
1984	640,000	1,400
1985	1,400,000	1,800
1986	1,900,000	2,000
1987	--- [a]	900 [b]
1988	570,000	240
1989	1,211,570	NS [c]
1990	480,055	NS
1991	399,368	NS
1992	414,288	NS
1993	980,224	20,312
1994 [d]	628,048	1,760

Source: Department of Fish and Game. All values are subject to revision.
[a] No Delta-wide survey.
[b] 3 to 14 mm fish.
[c] Not sampled.
[d] No sampling was done in Suisun Marsh after 1995. Data from 1995 will not be processed.

Striped Bass Tow-Net Survey

The striped bass tow-net index estimates the abundance of young striped bass when the average length of the fish is 38.1 mm (1.5 inch). The 38.1-mm size was selected because the tow-net is most efficient for fish of that length. Surveys are conducted every two weeks in Suisun Bay and the Delta until the index size is reached or exceeded. Samples are taken during an oblique ten-minute tow at a standardized boat speed. Due to variations in environmental conditions, survey dates vary from year to year in June, July, and August. Spring and summer conditions affect spawning time and larval growth and, hence, the time at which young become vulnerable to the sampling gear. Sampling begins when the young striped bass reach about 17.8 mm and continues until mean catch length is greater than 38.1 mm. Sampling stations are shown in Figure 10.

In 1997, only two surveys were conducted because striped bass reached 38.1 mm soon after 12 July (Table 5). The final Total Index of 1.6 (Total Suisun Index plus Delta Index), which was reached on 16 July, was low. The Delta Index of 1.0 was the second lowest on record since 1959, when DFG began calculating indices (Table 6, Figure 11). The Montezuma Slough Index of 0.1 was lower than any indices measured in Montezuma Slough in the last ten years. The low indices in 1997 were a continuation of the trend of low indices that began in 1995. Since 1995, indices were lower than ones predicted from flow and pumping (personal communication with Steve Foss, unreferenced, see “Notes”). The reasons for the low values remain unclear.

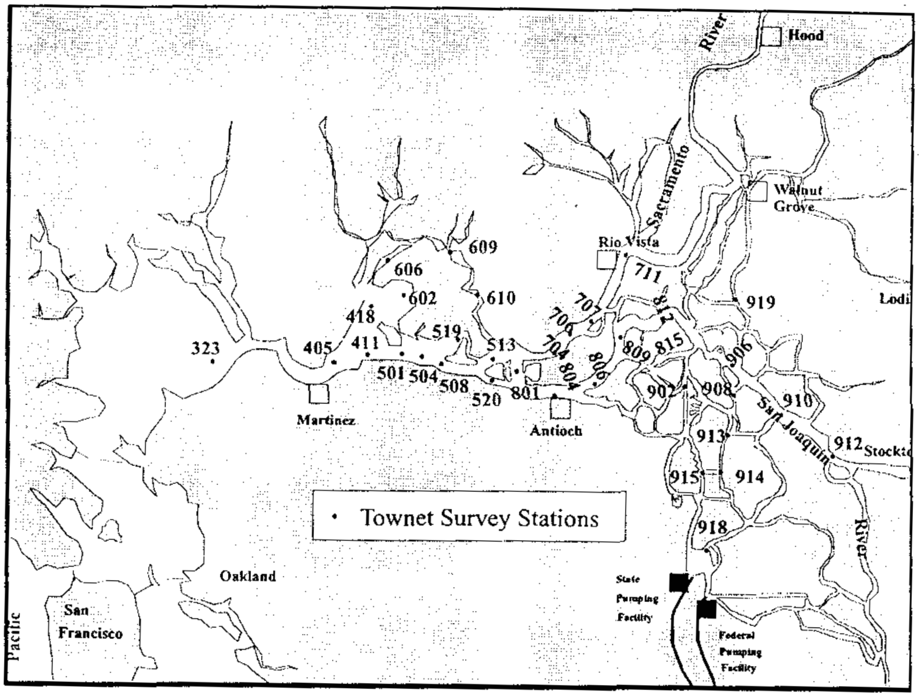

Figure 10 Striped bass tow-net survey stations (from Foss and Miller 1996)

Table 5 Striped bass abundance indices for Montezuma Slough, Suisun Bay, and the Delta from 1987 to 1997

Year	*Montezuma Slough Index*	*Suisun Bay Index*	*Total Suisun Index*	*Delta Index*	*Total Index*	*38.1 mm Index Date*
1984	--- [a]	--- [a]	20.0	6.3	26.3	13 Jul 84
1985	--- [a]	--- [a]	4.1	2.2	6.3	16 Jul 85
1986	--- [a]	--- [a]	41.1	23.8	64.9	09 Jul 86
1987	1.9	3.4	5.3	7.3	12.6	22 Jun 87
1988	<0.8	<0.7	0.7	3.9	4.6	24 Jul 88
1989	1.2	0.8	2.0	3.1	5.1	11 Jul 89
1990	0.8	0.6	1.5	2.8	4.3	18 Jul 90
1991	0.9	0.9	1.6	3.9	5.5	25 Jul 91
1992	1.8	2.2	4.0	6.6	10.6	26 Jun 92
1993	4.9	6.9	11.8	10.8	22.6	22 Jul 93
1994	0.9	2.7	3.6	7.0	10.6	10 Jul 94
1995 [b]	NA [c]	NA	NA	NA	NA	NA
1996	0.8	0.8	1.6	0.5	2.1	21 Jul 96
1997	0.1	0.5	0.6	1	1.6	16 Jul 97

[a] Data not available.
[b] No indices were set during water year 1995. Please see text for explanation and an estimated value of the Total Index.
[c] Not applicable.

Table 6 Results of striped bass tow-net surveys during 1997

	Survey 1 [a]		*Survey 2 [b]*		*Final Index [c]*
Sampling Site	*Catch*	*Index*	*Catch*	*Index*	*Index*
Montezuma Slough	124	1.5	16	0.2	0.1
Suisun Bay	74	2.3	21	0.7	0.5
Suisun Subtotal	198	3.8	37	0.9	0.6
Sacramento River	43	1.6	5	0.2	0.1
Lower San Joaquin	21	0.9	22	1.1	0.9
East Delta	8	0.1	1	0.0	0.0
South Delta	4	0.0	1	0.0	0.0
Delta Subtotal	76	2.6	29	1.3	1.0
Total	274	6.4	66	2.2	1.6
Station 340 (catch)					
Mean Length (mm)	33.4		37.1		38.1

[a] 27 June through 1 July 1997.
[b] 10 through 14 July 1997.
[c] 16 July 1997.

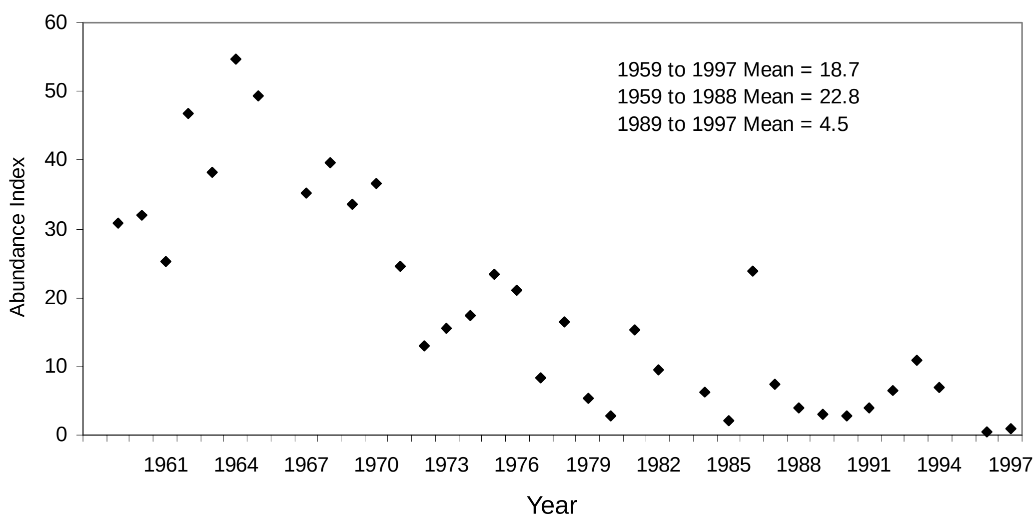

Figure 11 Striped bass 38.1-mm abundance indices for the Delta from 1959 to 1997

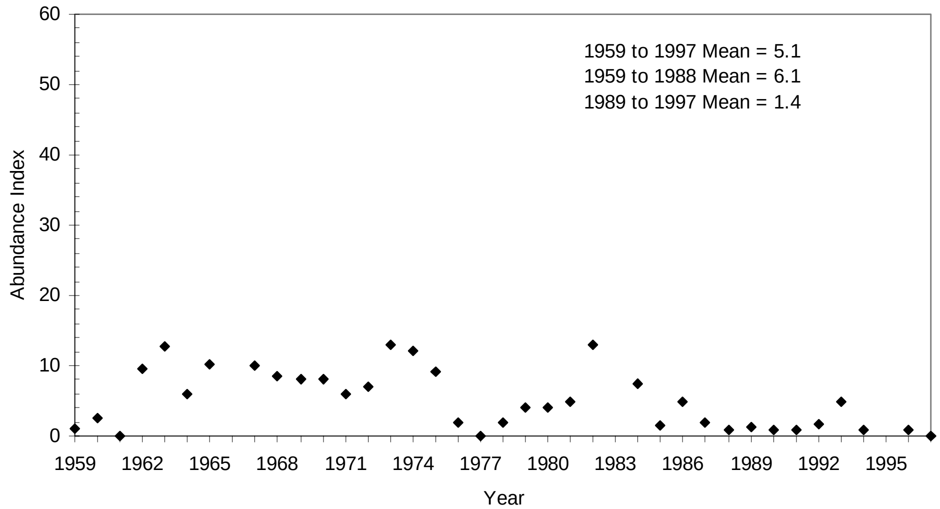

Figure 12 Striped bass 38.1-mm abundance indices for Montezuma Slough from 1959 to 1997

Since 1959, the striped bass index in Montezuma Slough has ranged from <1 to 13, with an average of 5.1 (Figure 12). The abundance index in the Delta has ranged from 0.5 to 54.7, with an average of 18.7 (see Figure 11). A gradual decrease in the average 38.1-mm striped bass abundance index has been observed in the Delta and Montezuma Slough since sampling began in 1959. The average abundance index in the Delta was 38.5 from 1959 to 1969, 18.2 from 1970 to 1979, 8.9 from 1980 to 1988, and 4.5 from 1989 to 1997. A decrease has also been observed in Montezuma Slough, where the average abundance index was 6.9 from 1959 to 1969, 6.3 from 1970 to 1979, 4.8 from 1980 to 1988, and 1.4 from 1989 to 1997. Since the decrease has been relatively constant over the last 30 years, it is unlikely that changes in abundance were due to installation and operation of the SMSCG. In general, increased abundance during most wet years indicates that Montezuma Slough is a relatively small, yet important habitat for juvenile striped bass.

Chapter 5
Juvenile Chinook Salmon Monitoring

Juvenile chinook salmon sampling in Montezuma Slough has not occurred since 1994. Staff constraints prevented researchers from conducting the juvenile chinook salmon sampling in Montezuma Slough in subsequent years. Also, usefulness of the data has been limited by variations in gear efficiency and small sample sizes. Consequently, no new data are presented in this section. DWR (1997a) provides a complete description of monitoring and analysis done to (1) determine the percentage of the chinook salmon population that use Montezuma Slough as a migration corridor and (2) estimate the magnitude of salmon losses associated with the SMSCG.

Chapter 6
Sampling by the University of California, Davis

Adult and Juvenile Sampling

Since 1980, DWR has contracted with UC Davis to monitor fish populations in Suisun Marsh. Originally, researchers conducted the study to do the following:

- Record long-term changes in fish populations due to environmental fluctuations and species introductions and add to the growing database on the estuary.

- Monitor distribution and abundance of seasonal species of Suisun Marsh, especially delta smelt, longfin smelt, chinook salmon, and splittail.

- Track the movement of exotic species, such as the shimofuri goby and the Asian clam.

With construction of the SMSCG, biologists expanded the sampling to study effects of the gates and other proposed changes in water circulation on fish populations. Scientists tracked trends in diversity and abundance and determined habitat requirements of marsh fishes and reported the information annually. The data have been used to evaluate indirect effects of SMSCG operation.

Overview of 1997 Results

Fish abundance in Suisun Marsh generally appeared low in 1997, suggesting that the long-term fluctuation at lower abundance levels continues. The decline began before the installation of the SMSCG and appears to have continued since their construction. Therefore, while the relationship between fish abundance and SMSCG operations is not well understood, the decline does not appear to be dependent on SMSCG operations.

All species but striped bass, shimofuri gobies, prickly sculpin, and tule perch were less abundant in 1997 than in 1996. Striped bass and shimofuri gobies accounted for 48% and 19%, respectively, of all fish captured in 1997. Matern and others (1998) attributed the higher levels of prickly sculpin to less saline conditions and suggested that while tule perch numbers increased temporarily in 1997, they have remained generally low since the peak abundance of shimofuri gobies in 1989. Shimofuri gobies and tule perch are captured in the same areas in Suisun Marsh.

Palaemon macrodactylus abundance increased from levels measured in 1995 and 1996. *Crangon franciscorum* reached the highest level seen since 1989, and mysid abundance increased over levels seen in 1995 and 1996. Typically, until 1988, striped bass and one of a number of native species ranked as the two most abundant fish in the marsh. Since 1988, however, striped bass and either shimofuri or yellowfin gobies, all introduced, dominated the Suisun Marsh fish community. If this trend continues, the fish assemblage in the marsh may be dominated solely by exotic species.

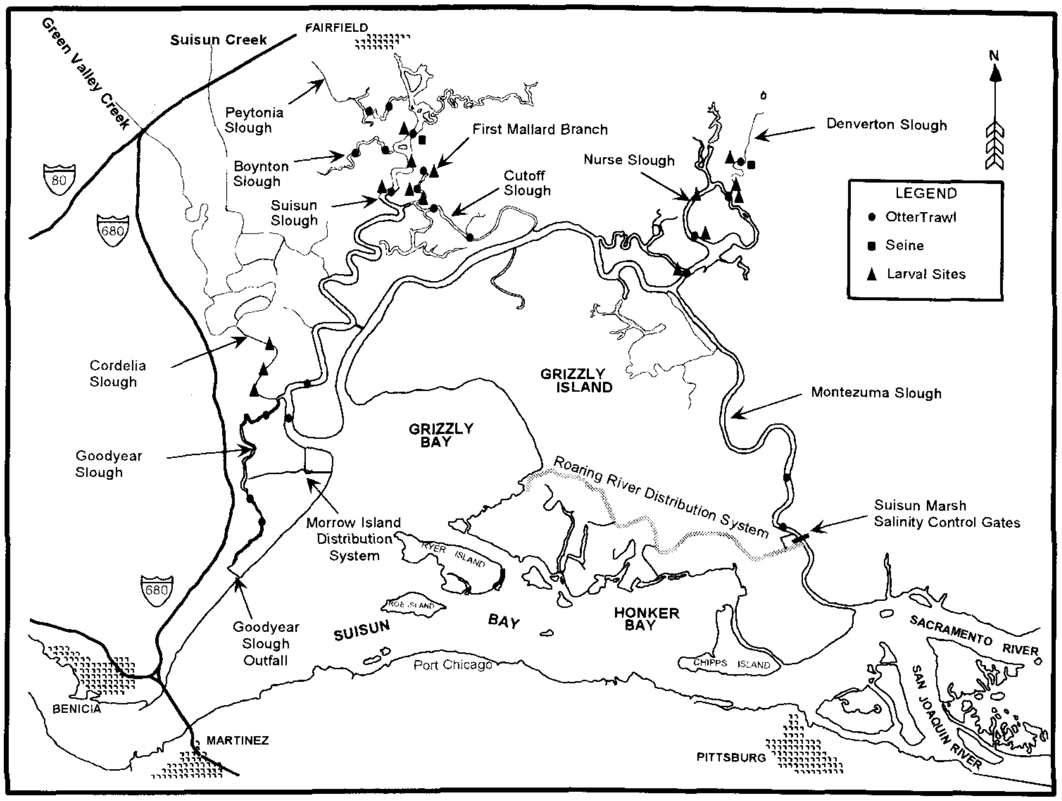

Figure 13 Location of fish monitoring stations in Suisun Marsh sampled by UC Davis

Methods

Monthly samples were taken year-round with a four-seam otter trawl with an opening of 1 m x 2.5 m, a length of 5.3 m, and mesh sizes tapering from 35-mm stretch in the body of the trawl to 6-mm stretch in the cod end. Biologists towed the trawl at 4 km/hr for five minutes in the small sloughs (seven to ten meters wide and one to two meters deep) and for ten minutes in large sloughs (100 to 150 meters wide and two to four meters deep). Seining was done with a beach seine ten meters long with a mesh size of 6 mm.

UC Davis researchers have trawled at 17 stations throughout Suisun Marsh and seined in Suisun Slough since 1980 (Figure 13). Fifteen of the stations were in the western marsh and two were in the eastern marsh, both downstream of the SMSCG. To provide more representative sampling of marsh species, in March 1994, researchers added two otter trawling sites in Nurse Slough, and two otter trawling sites and one seining site in Denverton Slough.

At all sites, captured fish were counted, up to 30 individuals of each species were measured to the nearest millimeter standard length, and all fish were returned to the slough. Fish captured in the net range from 12 to 600 mm standard length[2]. Researchers also recorded actual numbers of *C. franciscorum* and *P. macrodactylus* and estimated the abundance of Neomysis mercedis. Channel water salinity, temperature, and water clarity were recorded at each site. Tidal conditions were estimated using the *Tidelog* (National Oceanic Service and others 1996).

2. The capture of small fish is often dependent on abundance. The capture of larger fish seems to be dependent on species. For example, carp are typically the larger fish captured, and it appears that other species that are of similar size, like striped bass, avoid the net more effectively.

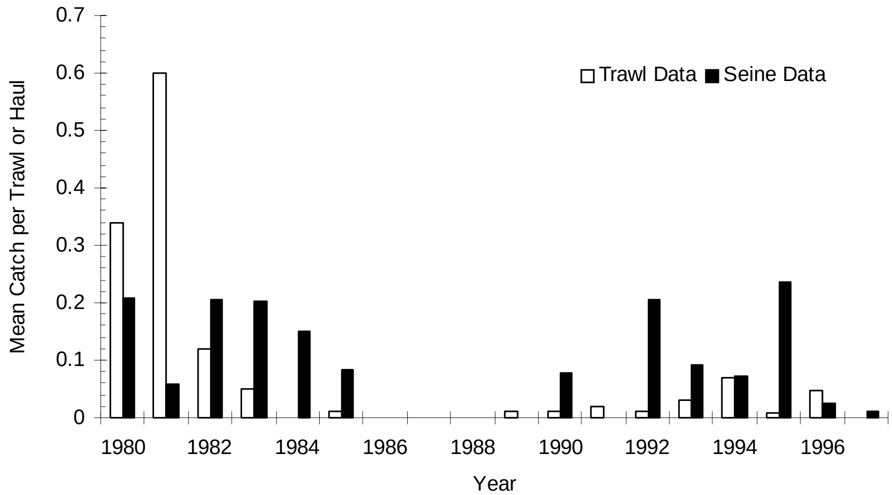

Figure 14 Catch per unit effort of delta smelt from 1980 to 1997

Fish and Invertebrates

Much of the following information is summarized from Matern and others (1998), who believe the data show both long-term and short-term changes in abundance. Since 1986, the overall abundance and diversity of fish have fluctuated at lower levels than in years before 1986. In 1997, the mean number of fish per trawl was almost two times the number in 1996, and the percentage of introduced species (75%) captured in the marsh continued to outnumber native species (25%).

Native Species

Delta Smelt

In general, the annual mean catch per trawl[3] has averaged 0.12 since 1980 and has ranged over the whole period from 0 to 0.60 (Figure 14). Annual mean catch per trawl of delta smelt peaked at 0.60 in the early 1980s. From 1984 to 1997, it was 0.05 or less, except in 1994 when it measured 0.07. Of the 472 delta smelt captured since 1980, only 49 were captured since 1983 (Table 7). Total otter trawl catch declined from 12 in 1996 to 0 in 1997. In 1997, researchers seined one delta smelt (not noted in the trawl data), for an annual mean catch per haul of 0.01. This was similar to the numbers captured in 1996 (0.02 per haul).

3. Annual mean catch per trawl is the total number of fish of a particular species captured in all the trawls in a one-year period, divided by the total number of trawls done in that year. For example, 12 delta smelt were captured in all the trawls in 1996, and 252 trawls were done in that year. The resulting annual mean catch per trawl is 12 divided by 252, or 0.05

Table 7 Catch per year for species collected in Suisun Marsh from 1980 to 1997. About twice as many trawls were done in 1980 and 1981.[a]

Species	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Delta smelt	157	229	28	9	0	1	0	0	1	1	1	5	3	7	16	2	12	0
Longfin smelt	3263	831	1573	200	553	150	25	110	195	129	242	21	3	3	6	82	8	5
Striped bass	5868	8746	2639	3871	2286	2290	1948	1417	719	1118	383	1602	2682	967	792	1451	1295	3032
Splittail	3612	1765	1153	467	190	151	683	441	169	108	80	197	134	62	51	260	434	227
Yellowfin goby	1079	222	204	22	906	173	560	274	108	381	154	265	317	3261	174	2161	248	182
Shimofuri goby	(not present in marsh until 1985)					2	0	45	284	1268	855	657	352	118	463	117	48	1174
Prickly sculpin	1810	644	647	1137	125	74	362	51	112	38	11	83	137	242	68	707	511	531
Staghorn sculpin	354	369	31	9	39	98	54	40	96	76	52	162	18	14	19	271	51	48
Sacramento sucker	508	607	168	147	98	146	99	68	50	21	21	6	7	18	19	34	63	58
Tule perch	1893	2364	1555	100	109	494	580	1219	1289	204	186	182	210	96	158	93	85	251
Number of trawls	456	384	243	188	143	200	155	202	218	139	187	205	202	202	228	245	252	252

[a] Source: Matern and others 1998.

Longfin Smelt

Matern and others (1998) reported that longfin smelt catch has declined over time (Figure 15). From 1980 to 1985, longfin smelt abundance fluctuated widely at higher levels than observed currently. The highest annual mean was in 1980, at 7.16 per trawl. Annual mean catch fluctuated at levels higher than 1.00 until 1985, remained below 1.00 through 1989, increased to 1.29 in 1990, and declined to 0.33 or less through 1997. The increase in total catch in 1990 consisted of high numbers of fry. Scientists believe the prolific 1990 spawn did not alter the general decline, because low numbers of longfin smelt adults and fry were captured in subsequent years. In 1997, researchers captured five longfin smelt in the marsh by trawl. No longfin smelt were caught in the beach seines. In the early years of sampling, from 1980 to 1983, longfin smelt were caught as adult upstream migrants during fall and winter. From 1984 to 1993, researchers captured most longfin smelt as newly spawned emigrants in the spring. However, from 1994 to 1997, they captured longfin smelt from August to February, with most captured in October and November.

Chinook Salmon

From 1980 to 1989, scientists captured chinook salmon by trawling in all but two years (Figure 16). In 1995, they captured chinook salmon for the first time since 1989. Since 1980, annual mean abundance of chinook salmon has ranged from 0 to 0.08 fish per trawl. Chinook salmon captured in the trawl have ranged in size from 30 to 370 mm fork length. The beach seine data and the trawl data show that chinook salmon annual mean abundance has fluctuated. Typically, researchers captured more chinook salmon in beach seines than in otter trawls. The size of salmon captured in the beach seines has ranged from 30 to 101 mm fork length. The annual mean catch per haul declined from 0.67 in 1995 to 0.01 in 1997. All the salmon were captured from January to April and were classified as fall-run based on DFG daily size criteria. The majority of chinook salmon was captured at the seining beach in Denverton Slough.

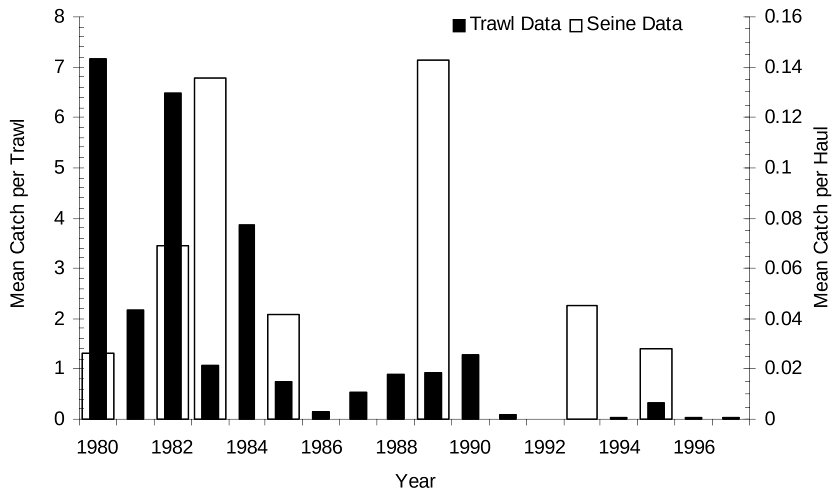

Figure 15 Catch per unit effort of longfin smelt from 1980 to 1997

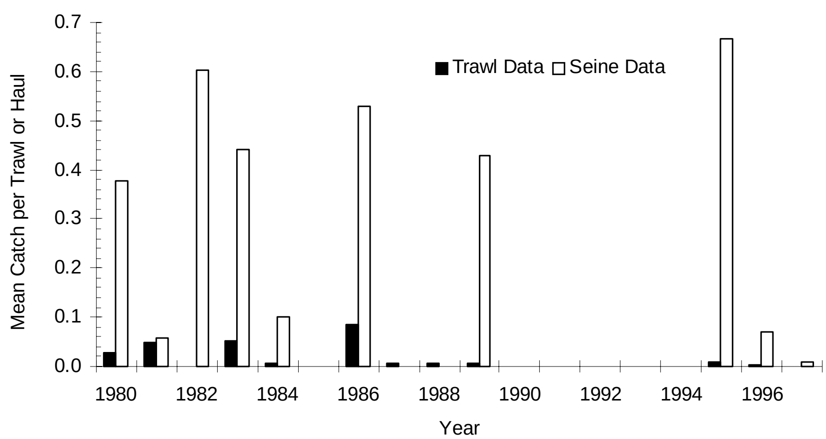

Figure 16 Catch per unit effort of chinook salmon from 1980 to 1997

Splittail

Catches of splittail in 1997 were lower than in some years in the 1980s (Figure 17). High numbers were caught from 1980 to 1983 (annual mean catch of 2.48 to 7.92 per trawl) and in 1986 and 1987 (4.41 and 2.18 per trawl, respectively). In other years, annual mean catch per trawl ranged from 0.22 to 1.33. The 1995 mean catch of 1.06 per trawl was the highest since 1987. This was an increase from the annual mean low of 0.22 fish per trawl in 1994. The 1997 total catch was 227, with a mean annual catch of 0.90, similar to levels seen in the late 1980s and early 1990s. An additional 107 individuals were captured in the beach seines and the annual mean catch per haul was 1.27.

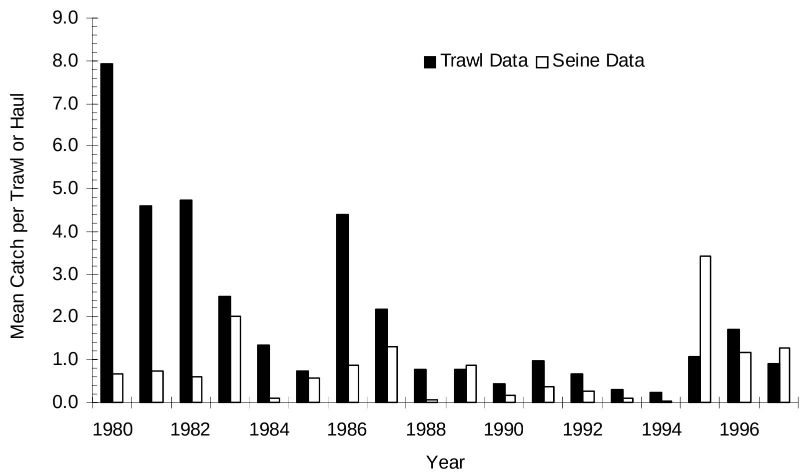

Figure 17 Catch per unit effort of splittail from 1980 to 1997

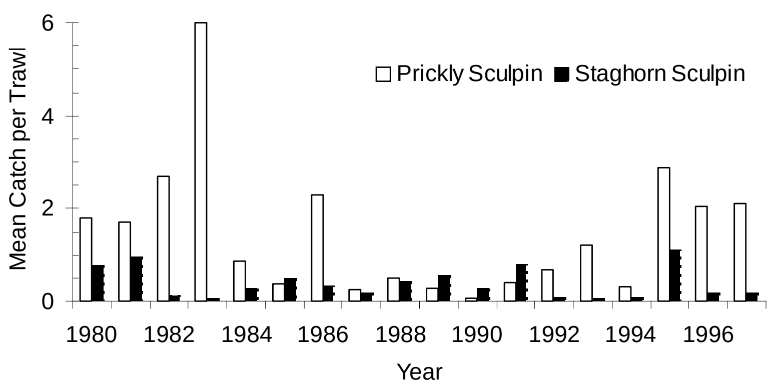

Figure 18 Mean catch per trawl of prickly sculpin and staghorn sculpin from 1980 to 1997

Prickly Sculpin

Prickly sculpin populations respond strongly to changes in outflow (Matern and others 1997). High outflow years produced peaks in annual mean catch per trawl of 6.05 in 1983, 2.34 in 1986, 1.20 in 1993, and 2.89 to 2.03 from 1995 to 1997 (Figure 18). From 1980 to 1983, abundance was high, with mean catches per trawl of 1.68 to 6.05. From 1984 to 1994, annual mean catch per trawl was 0.87 or less, except for peaks in 1986 and 1993. The 1997 mean catch per beach seine haul was 0.19.

Staghorn Sculpin

Catches of staghorn sculpin are typically lower than prickly sculpin. The annual mean catch per trawl of staghorn sculpin has exceeded those of prickly sculpin in only four years, 1985, 1989, 1990, and 1991. The staghorn sculpin annual mean catch per trawl peaked at 0.78 in 1980, 0.96 in 1981, 0.79 in 1991, and 1.11 in 1995 (see Figure 18). From 1982 to 1990, annual mean catch per trawl fluctuated at or below 0.55. From 1992 to 1994, annual mean catch per trawl remained at or below 0.09. The 1995 mean catch per trawl (1.11) was the highest since the sampling began, but levels declined to 0.12 in 1997. Researchers captured an additional 1.74 staghorn sculpins per haul in the beach seines.

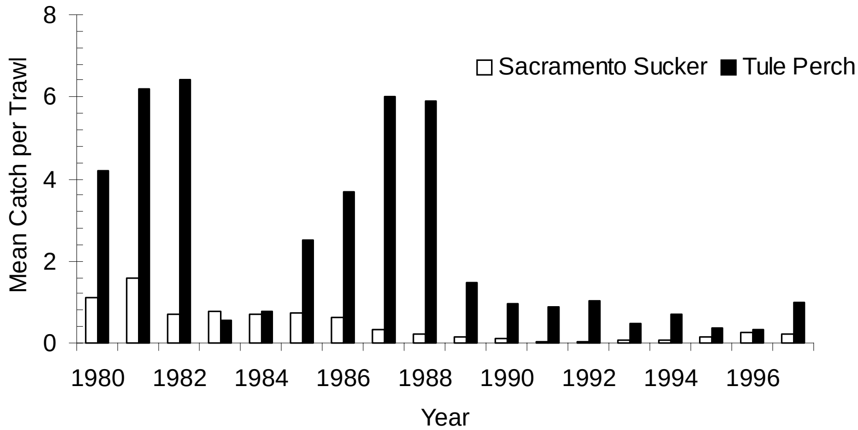

Figure 19 Mean catch per trawl of Sacramento sucker and tule perch from 1980 to 1997

Sacramento Sucker

Since the early 1980s, Sacramento sucker abundance has declined (Figure 19). The highest annual mean catch per trawl was 1.58 in 1981. Since then, annual mean catch generally declined to a low of 0.03 per trawl through 1992. In 1993 and 1994, annual mean catch per trawl was less than 0.10. The 1997 mean catch per trawl of Sacramento sucker was 0.23. Scientists captured an average of 0.10 individuals per haul in the beach seines in 1997.

Tule Perch

Tule perch are considered year-round residents of the marsh. For 12 of the 19 years of sampling, tule perch were ranked one of the four most abundant species in Suisun Marsh. Tule perch were captured most often in the smaller sloughs, possibly a result of the otter trawl efficiency in these areas. Annual mean tule perch abundance peaked from 1980 to 1982 at 4.15 to 6.40 fish per trawl and declined to 0.53 in 1983 and to 0.76 in 1984 (see Figure 19). Abundance peaked again in 1987 (6.03) and 1988 (5.91). Average catches since 1989 have ranged from 0.38 to 1.04. The 1997 mean catch per trawl was 1.00 and the annual mean number of tule perch per beach seine haul was 0.32. Matern and others (1997) hypothesize that decreases in tule perch abundance may be due in part to competition with exotic gobies, which inhabit the same areas as tule perch.

Pacific Lamprey

In 1995, researchers captured Pacific lamprey for the first time since 1992. Since 1980, they captured Pacific lamprey in 9 of 19 years of sampling. Annual mean abundance has ranged from 0 to 0.08 per trawl (Figure 20). The 1997 mean abundance measured less than 0.01.

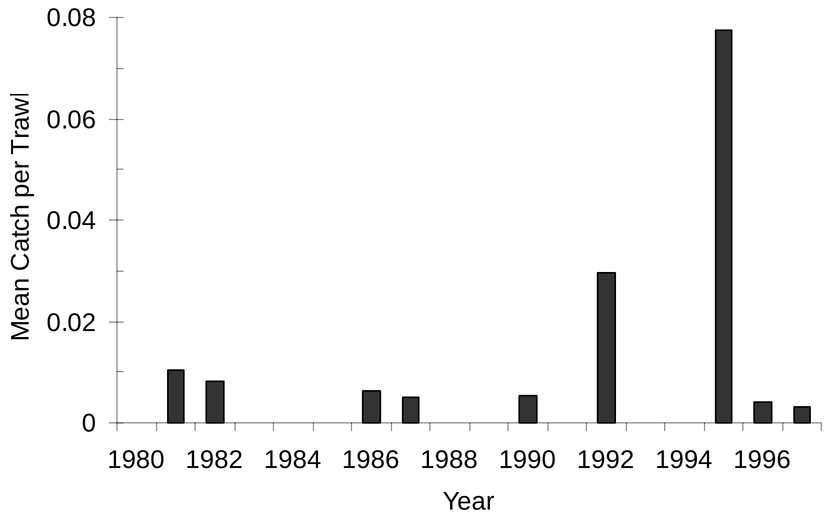

Figure 20 Mean catch per trawl of Pacific lamprey from 1980 to 1997

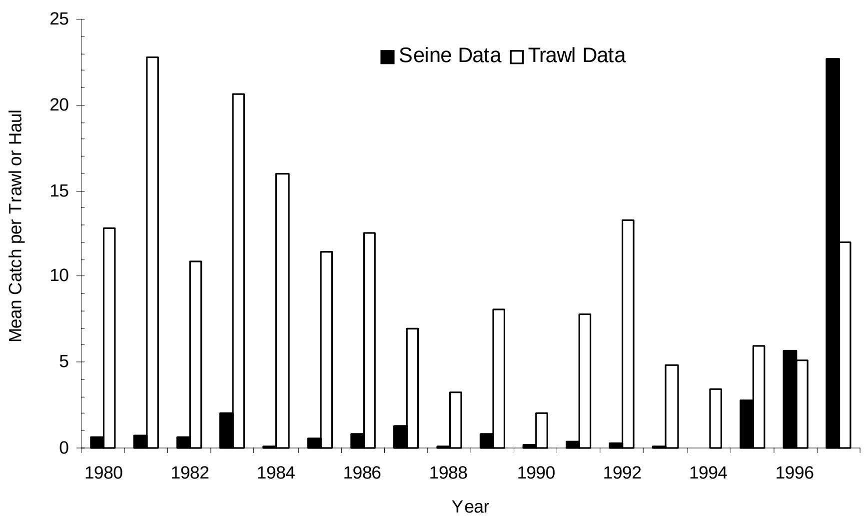

Figure 21 Catch per unit effort of striped bass from 1980 to 1997

Introduced Species

Striped Bass

Striped bass was the most abundant fish caught in all years of the study, except in 1988, 1989, 1990, 1993, and 1995 (see Table 7). Overall, striped bass catch declined from levels in the early 1980s, and annual mean catch ranged from 1.87 to 21.78 (Figure 21). Annual mean catch per trawl fluctuated at or above 10.40 through 1986. From 1987 to 1997, the annual mean catch per trawl fluctuated at or below 7.57, except for peaks of 13.28 and 12.03 in 1992 and 1997, respectively. An additional 1,906 striped bass were captured in the beach seines and the annual mean catch per haul was 22.69 in 1997.

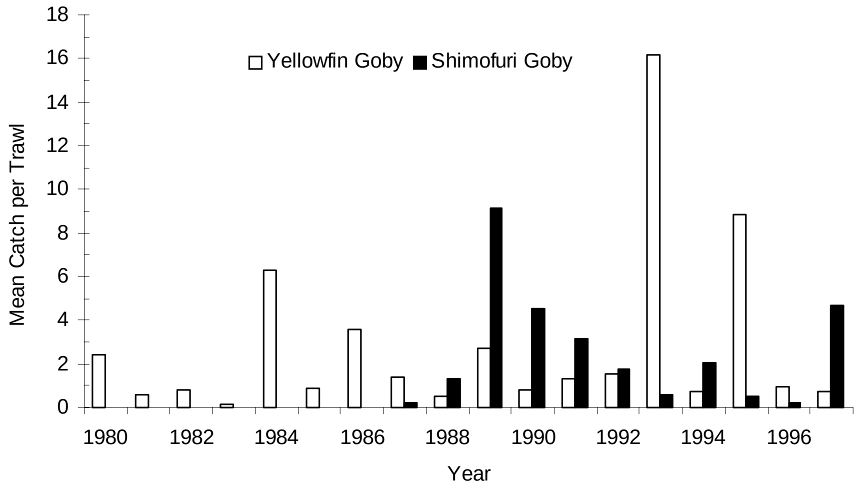

Figure 22 Annual mean catch per trawl of yellowfin goby and shimofuri goby

Yellowfin Goby

The annual mean catch per trawl of yellowfin goby has ranged from 0.12 to 16.14 and has had three major peaks since 1980 (Figure 22). Annual mean catch per trawl peaked at 6.34 in 1984. From 1985 to 1992, annual mean catch fluctuated from 0.50 to 3.61 fish per trawl. Abundance of yellowfin goby reached its highest level in 1993, with an annual mean of 16.14 fish per trawl. A third peak in occurred in 1995, when the annual mean catch per trawl rose to 8.82. The 1997 mean catch was 0.72, similar to levels seen in 1990 and 1994. An additional 611 were captured in the beach seines and the annual mean catch per haul was 7.27.

Shimofuri Goby

Shimofuri gobies were first captured in Suisun Marsh in 1985. Their annual mean abundance has ranged from 0 to 9.12 fish per trawl (see Figure 22). The annual mean catch per trawl was at or below 2.03 from 1985 to 1988 and again from 1992 to 1996. The 1997 mean catch per trawl was 4.66, similar to levels seen in 1990. In 1997, researchers captured an average of 3.26 shimofuri gobies per beach seine haul.

Macroinvertebrates

Mean catch per trawl of the bay shrimp *Palaemon macrodactylus* (introduced species) and *Crangon franciscorum* (native species) has fluctuated since 1980 (Figure 23). Biologists captured more *P. macrodactylus* in lower-salinity environments than *C. franciscorum* (Matern and Moyle 1994). From 1981 to 1997, annual mean abundance levels of *P. macrodactylus* were 1.50 to 24.00 per trawl. In 1997, *P. macrodactylus* annual mean abundance levels were 3.40 per trawl, similar to levels seen in 1992 and 1994.

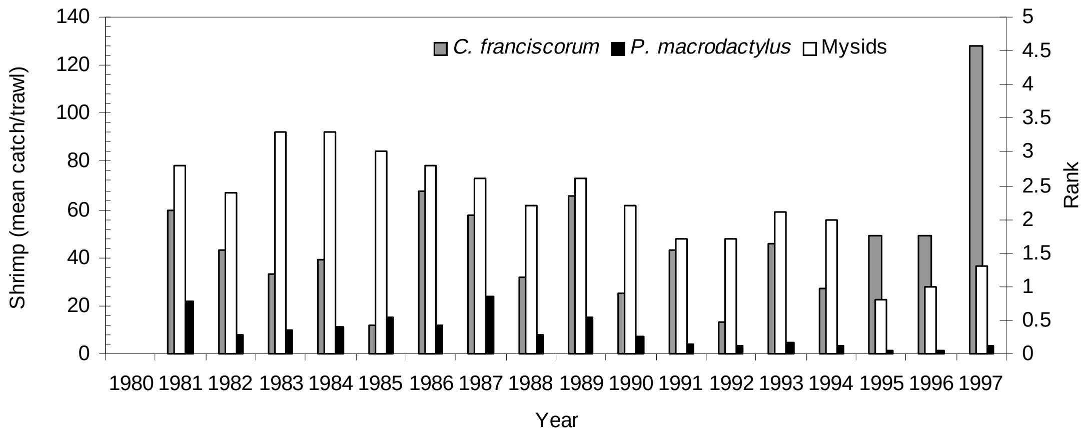

Figure 23 Mean catch per trawl of *Crangon franciscorum* and *Palaemon macrodactylus* and average abundance rankings for mysids

From 1981 to 1995, annual mean abundance of *C. franciscorum* ranged from 12 to 128 individuals per trawl. *Crangon franciscorum* catches peaked in 1997 at the highest level measured (128 per trawl) since sampling began in 1979.

From 1981 to 1991, the annual average abundance ranking[4] of *Neomysis mercedis* (native species) was 1.7 to 3.3. In 1992, an Asian mysid, *Acanthomysis* sp., invaded the estuary. Because it is not easily distinguishable from *N. mercedis* in the field, the relative abundance of the two invertebrates is unknown. From 1992 to 1997, the annual mean ranking for the two mysids ranged from 0.8 to 2.1. The 1997 mean rank (1.3) was the third lowest recorded since sampling began.

Larval Fish

Since 1994, DWR has contracted with UC Davis to conduct a larval fish survey in Suisun Marsh. The three goals for the study are as follows:

- To augment the understanding of the marsh fish communities with information on larval stage.
- To determine the extent to which the relatively undisturbed marsh habitats are used by fish for spawning and rearing.
- To determine if special-status species such as delta smelt, longfin smelt, and splittail are using the marsh for spawning and rearing.

4. Rank 1 represents less than three individuals per trawl. Ranks 2, 3, and 4 represent 3 to 50 individuals, 51 to 200 individuals, and 201 to 500 individuals, respectively. Rank 5 represents more than 500 individuals per trawl.

Overview of 1997 Results

During the 1997 sampling, biologists captured the greatest number of larvae in Suisun Slough (15,798) and Denverton Slough (15,198). In 1994 and 1996, the highest catches were in First Mallard Branch, and in Suisun Slough in 1995. The greatest diversity of species was in First Mallard Branch from 1995 to 1997 and in Cordelia Slough in 1994. As in 1996, the difference in species diversity between sloughs in 1997 was small: 12 species were captured in Cordelia Slough, 11 in Denverton, 9 in Nurse Slough, 13 in First Mallard Branch, and 12 in Suisun Slough. Clearly, a variety of locations in the Suisun Marsh may provide suitable spawning and rearing habitat for several species and families. From 1994 to 1997, longfin smelt and delta smelt used the marsh for spawning and rearing, while splittail larvae were only captured in 1995 and 1996.

Methods

The study period has varied somewhat over the four years. In 1994, biologists sampled for larval fish once a week in Suisun Marsh from 15 April to 17 June. In 1995, weekly sampling occurred from 26 February to 15 June. In 1996, sampling occurred weekly from 2 February to 11 June, and in 1997, from 2 February to 5 June.

The net used for sampling is mounted on a sled. It is made of 505-micron mesh, and measures 0.525 square meters at the mouth, and is three meters long. Researchers made three replicate tows in the middle of the channel just under the water surface in First Mallard Branch, and Suisun, Nurse, Denverton, and Cordelia sloughs (see Figure 13).

In 1994, tows were ten minutes except for five-minute tows in First Mallard Branch. Since 1995, biologists reduced all tows to five minutes because of large samples sizes in 1994. A flow meter attached to the sled measured the volume of water that passed through the net. Water temperature, salinity, and clarity were measured at each site. The researchers preserved all samples in 10% formaldehyde tinted with rose bengal. All fish were counted unless a sample contained more than 1,000 individuals, in which case the researchers estimated the number to the nearest 100. When more than 400 fish were captured in a replicate, researchers randomly subsampled up to 200 fish per jar and identified the fish to the family level. In samples with more than 400 fish, number of fish within each species-family category was adjusted for extra fish in the sample by the following formula:

$$\frac{(\text{total fish identified} + \text{extra fish})}{\text{total fish identified}} \times \text{number of fish identified in each species-family category}$$

If historical results from the otter trawling indicated that only one species from a family occurred in the marsh, then all individuals captured in that family were assumed to be the known species. However, smelt were identified to the species level and splittail were identified within the cyprinids. All data from the 1997 larval sampling are presented and evaluated in Matern and others (1998).

Water Quality

Water quality varied more between sloughs in 1997 than in 1995 or 1996. Salinity in 1997 was 0.4 to 4.9 ppt and differed by less than 2.4 ppt between sloughs. The lowest monthly salinity (0.4 ppt) was measured in Nurse Slough in February. The highest monthly salinity (4.9 ppt) was measured in Cordelia Slough in June (Figures 24 and 25, Table 8).

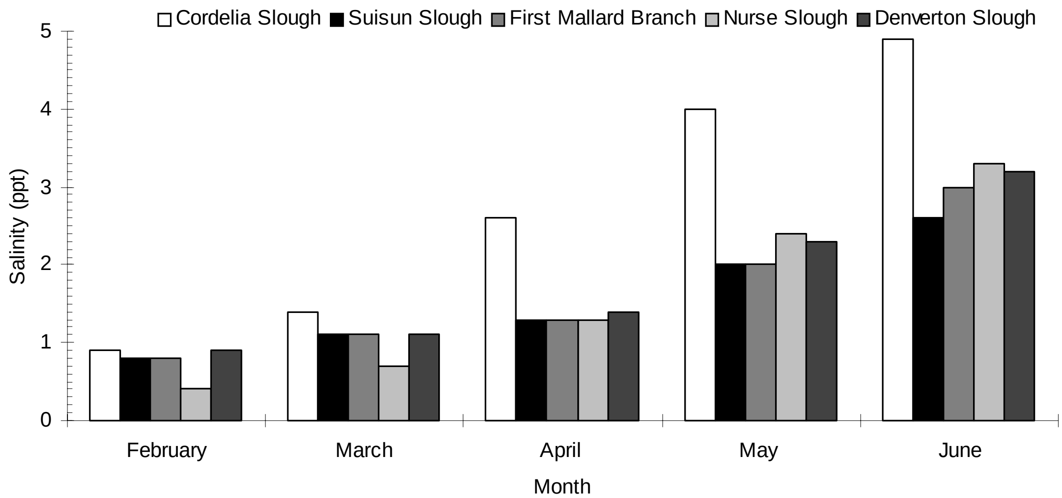

Figure 24 Salinity in each slough during larval sampling in 1997

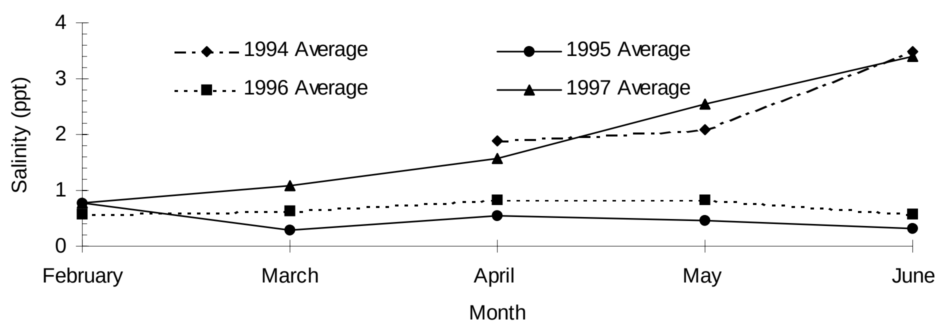

Figure 25 Average monthly salinity during larval sampling from 1994 to 1997

Table 8 Range of salinity measurements during larval sampling from 1994 to 1997. Units are parts per thousand.

	1994		*1995*		*1996*		*1997*	
Month	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*
February	NA[a]	NA	0.3	1.1	0.4	0.7	0.4	0.9
March	NA	NA	0.2	0.4	0.5	0.8	0.7	1.4
April	1.1	4.1	0.1	0.8	0.6	0.9	1.3	2.6
May	1.4	4.2	0	0.7	0.5	0.9	2.0	4.0
June	2.4	6.5	0	0.6	0.3	0.8	2.6	4.9

[a] NA indicates not applicable.

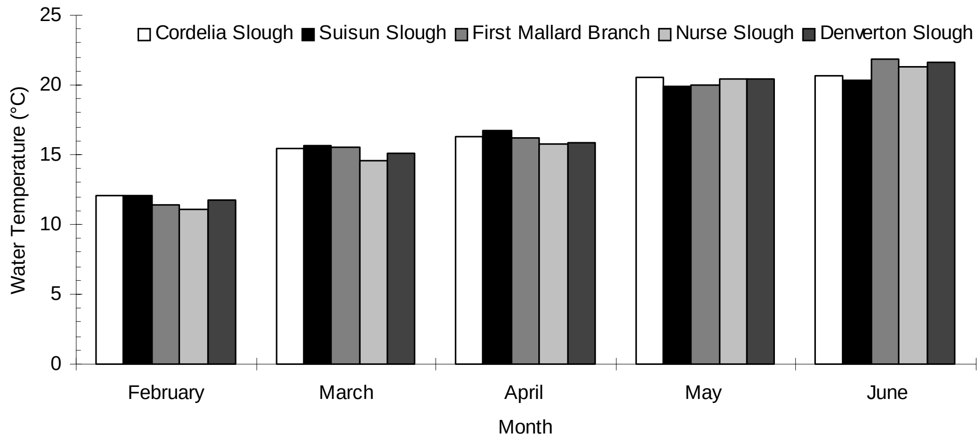

Figure 26 Water temperature in each slough during larval sampling in 1997

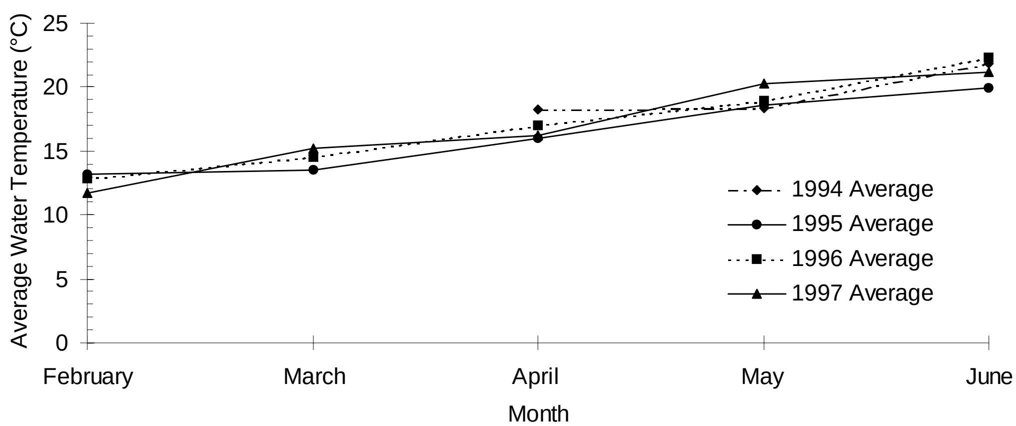

Figure 27 Average monthly water temperature during larval sampling from 1994 to 1997

In 1997, water temperature in all sloughs was 11.1 to 21.8 °C and differed by no more than 1.5 °C between sloughs in any given month (Figures 26 and 27, Table 9). Monthly average water temperatures measured from 1994 to 1997 were similar.

During 1997 sampling, the range in water clarity, as estimated by Secchi disk depth, was 10.9 to 20.3 cm (Figures 28 and 29, Table 10). No slough was consistently the highest or lowest in water clarity.

Fish

During 1997 sampling, researchers captured 12 families and at least 17 species (Table 11). Since 1995, the greatest abundance of larvae has occurred in May; in 1994 the greatest abundance occurred in June (Figure 30). The greatest numbers of larvae were in Suisun Slough in 1997, and in First Mallard Branch from 1994 to 1996 (Figure 31).

Table 9 Range of water temperatures during larval sampling from 1994 to 1997. Units are degrees Celsius.

	1994		*1995*		*1996*		*1997*	
Month	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*
February	NA [a]	NA	12.7	13.8	12.4	13.3	11.1	12.1
March	NA	NA	12.8	14.1	14.2	14.8	14.6	15.6
April	18.0	18.8	15.5	16.5	16.8	17.2	15.8	16.7
May	17.7	18.8	17.5	19.1	18.1	19.7	19.9	20.5
June	21.2	22.4	19.3	20.2	21.8	23.5	20.3	21.8

[a] NA indicates not applicable.

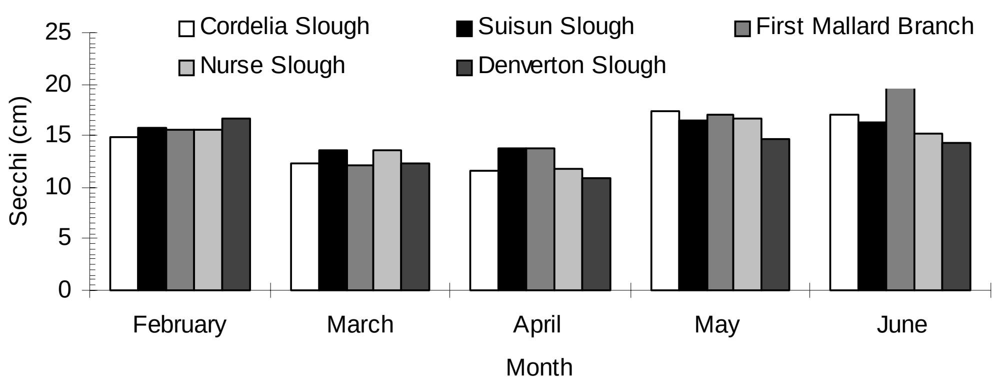

Figure 28 Water clarity in each slough during larval sampling in 1997

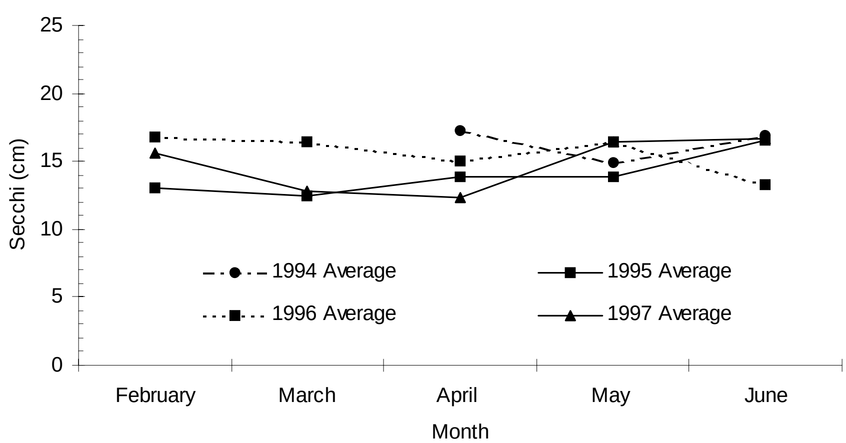

Figure 29 Average monthly water clarity during larval sampling from 1994 to 1997

Table 10 Range of water clarity during larval sampling from 1994 to 1997. Measurements are Secchi disk depth and units are in centimeters.

	1994		*1995*		*1996*		*1997*	
Month	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*
February	NA [a]	NA	12.0	15.0	14.0	20.1	14.8	16.7
March	NA	NA	10.0	15.0	15.1	18.6	12.2	13.6
April	15.0	21.4	12.0	15.0	13.3	16.7	10.9	13.8
May	14.0	16.4	11.0	15.0	14.6	19.5	14.6	17.4
June	16.0	18.1	14.0	19.0	12.3	14.7	14.3	20.3

[a] NA indicates not applicable (no sampling was done).

Table 11 Families and species captured during larval fish sampling in 1997

Family	*Species*	*Origin*
Cottidae	prickly sculpin	Native
Gobiidae	shimofuri goby	Introduced
	yellowfin goby	Introduced
Percichthyidae	striped bass	Introduced
Clupeidae	American shad	Introduced
	threadfin shad	Introduced
	Pacific herring	Native
Osmeridae	delta smelt	Native
	longfin smelt	Native
Engraulidae	northern anchovy	Native
Cyprinidae	splittail	Native
	carp	Introduced
Catostomidae	Sacramento sucker	Native
Gasterosteidae	threespine stickleback	Native
Atherinidae	inland silverside	Introduced
Centrarchidae	white crappie	Introduced
Pleuronectidae		Not indicated

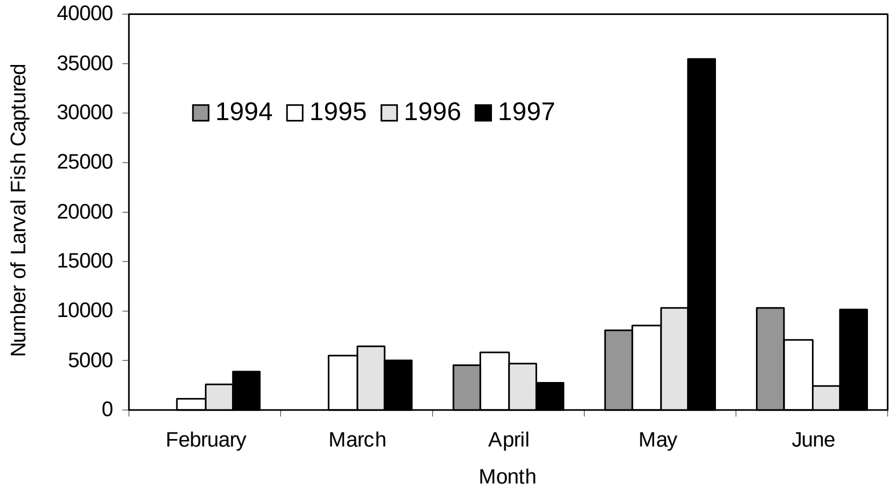

Figure 30 Number of larval fish captured each month from February through June, 1994 to 1997

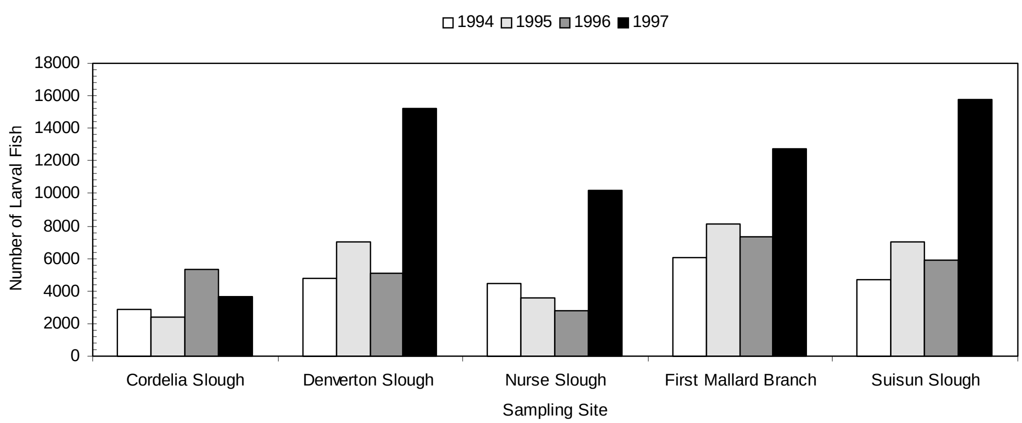

Figure 31 Number of larval fish captured in each slough from February through June, 1994 to 1997

In 1997, the most abundant family was the Gobiidae (Table 12). Subsampling revealed the presence of shimofuri and yellowfin gobies. Scientists captured the most larval Gobiidae in Denverton Slough in 1997, while peak numbers were seen in Suisun Slough in 1995 and 1996, and in First Mallard Branch in 1994 (Figure 32). The highest frequency of gobies in 1997 occurred in May as it did in 1995 and 1996, while June showed the highest abundance in 1994 (Figure 33).

Prickly sculpins were the second most abundant larval species captured in 1997. In 1997, the greatest abundance of larval sculpins was seen in First Mallard Branch, while in previous years the greatest numbers were captured in Denverton Slough or First Mallard Branch (Figure 34). Larval abundance peaked in March from 1995 to 1997 (Figure 35). No comparison was made with the data collected in 1994, since 1994 sampling did not begin until April.

Table 12 Number of larval fish captured in Suisun Marsh from 2 February through 5 June 1997

Family or Species	*February*	*March*	*April*	*May*	*June*	*Total*
Gobiidae	0	9	577	34258	10149	45263
Cottidae	3594	4171	1578	437	0	9780
Longfin smelt	255	731	261	26	0	1273
Striped bass	0	0	120	441	11	573
Northern anchovy	0	0	0	229	2	231
Clupeidae	0	31	118	47	12	208
Threespine stickleback	46	9	0	2	1	58
Inland silverside	0	0	8	13	29	50
Sacramento sucker	1	9	22	2	0	34
Carp	0	1	11	15	0	27
Delta smelt	0	0	0	20	0	20
White crappie	0	0	0	14	0	14
Pleuronectidae	0	0	6	1	0	7
Sacramento blackfish	0	0	1	0	0	1
Total	3896	4961	2702	35505	10204	57539

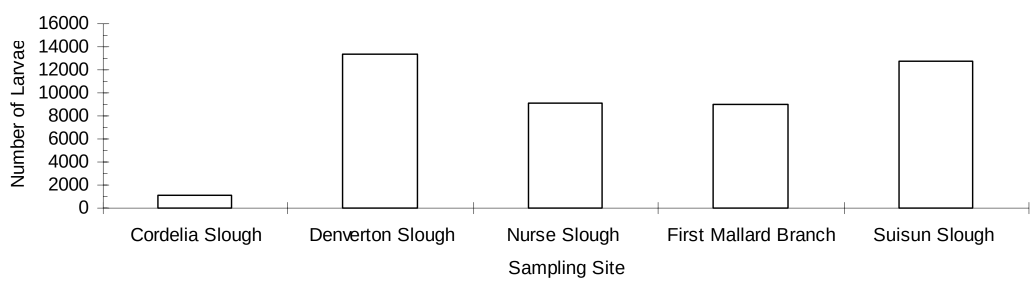

Figure 32 Number of larval Gobiidae captured in each slough from February through June 1997

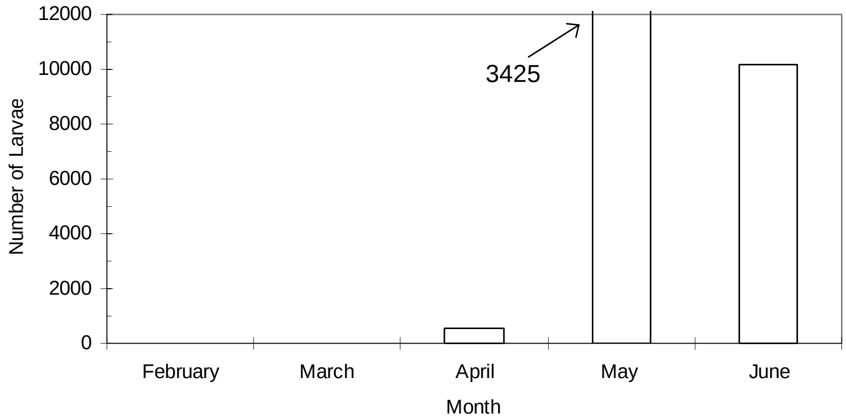

Figure 33 Number of larval Gobiidae captured each month from February through June 1997

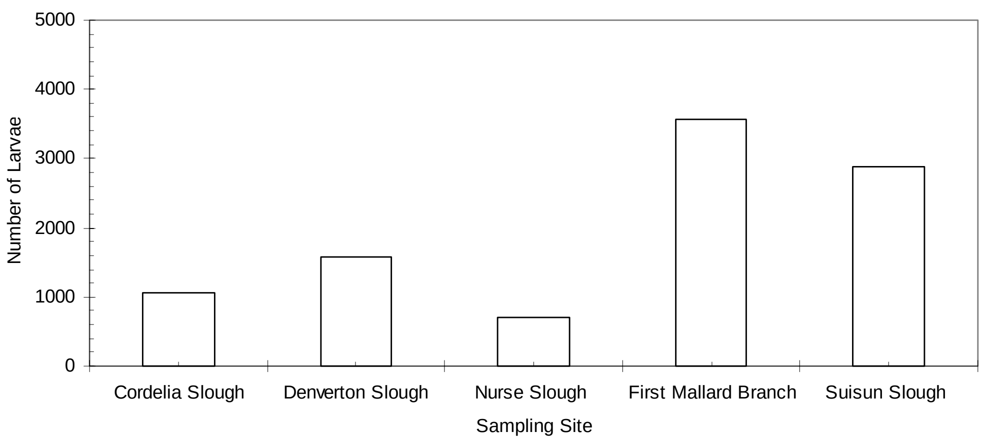

Figure 34 Number of larval Cottidae captured in each slough from February through June 1997

In 1997, the third most abundant family was the Osmeridae, represented by longfin smelt and delta smelt. Most delta smelt were captured in Denverton Slough in 1997 and in Nurse Slough in previous years (Figure 36). From 1994 to 1997, peak abundance of delta smelt occurred in May (Figure 37). Since 1995, UC Davis researchers captured the most longfin smelt in Cordelia Slough. In 1997, peak longfin smelt numbers were measured in March rather than February, as seen in 1995 and 1996.

UC Davis researchers also calculated the densities of delta smelt and longfin smelt captured in all sloughs in 1997. Because delta smelt were only caught in May, delta smelt density averaged 0 fish per cubic meter over the five months and ranged from 0 to 0.072 fish/m^3. The average delta smelt density in all the sloughs sampled in May was 0.002 fish/m^3. Longfin smelt densities ranged from 0 to 1.947 fish/m^3 and averaged 0.028 fish/m^3 from February to May. UC Davis biologists did not calculate densities for any other species.

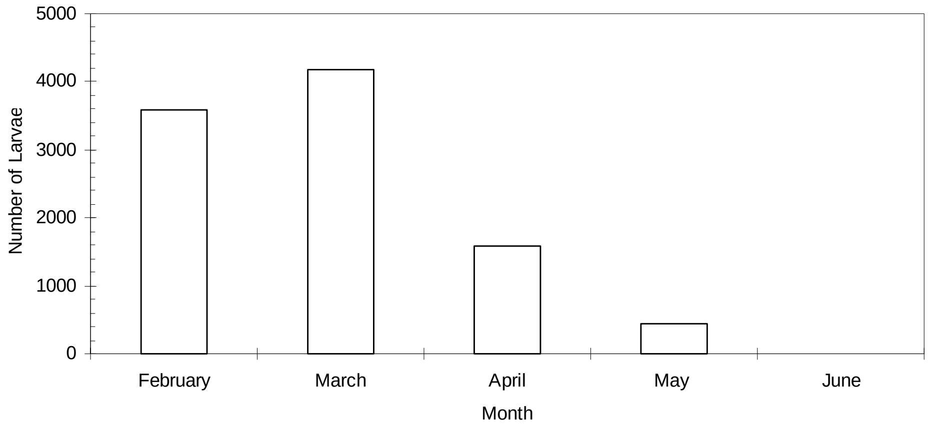

Figure 35 Number of larval Cottidae captured each month from February through June 1997

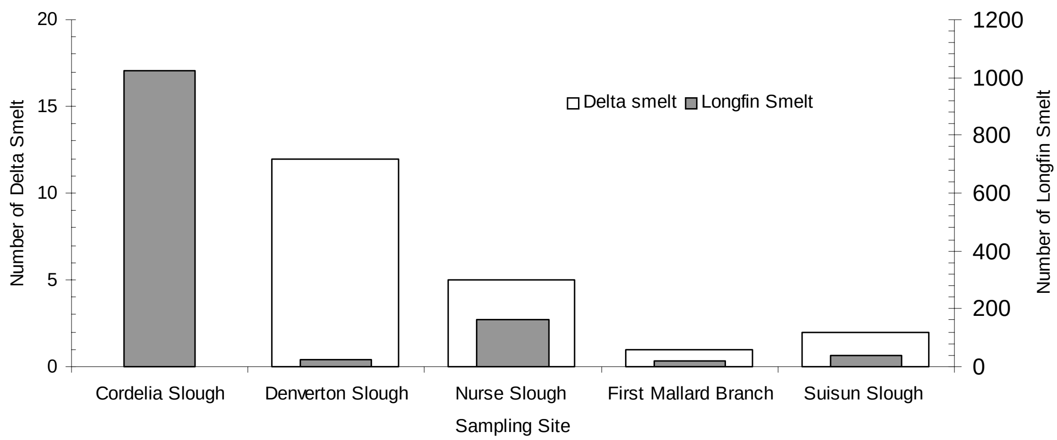

Figure 36 Number of larval osmerids captured in each slough from February through June 1997. Osmerids were 4.5 to 25.5 mm total length.

In 1997, the fourth most abundant family was the Percichthyidae, represented by striped bass. As in 1995 and 1996, researchers captured the most striped bass in Cordelia Slough (Figure 38). In 1994, the greatest numbers were measured in Denverton Slough. In 1996 and 1997, striped bass larvae were not captured until April; catches peaked in May in 1994, 1996, and 1997 (Figure 39). In 1994, biologists captured striped bass larvae in April, but not until May in 1995. Striped bass larvae numbers peaked in June in 1995.

Northern anchovy and clupeids followed striped bass in abundance. Northern anchovy were captured for the first time since the sampling began in 1994. Peak abundance occurred in May in Cordelia Slough (Figures 40 and 41). Clupeidae were represented by American shad, threadfin shad, and Pacific herring. Researchers captured clupeids most often in Cordelia Slough in 1997 and 1994, and in First Mallard Branch in 1995 and 1996 (see Figure 41). Peak clupeid abundance occurred in April rather than in May and June as in previous years (see Figure 40).

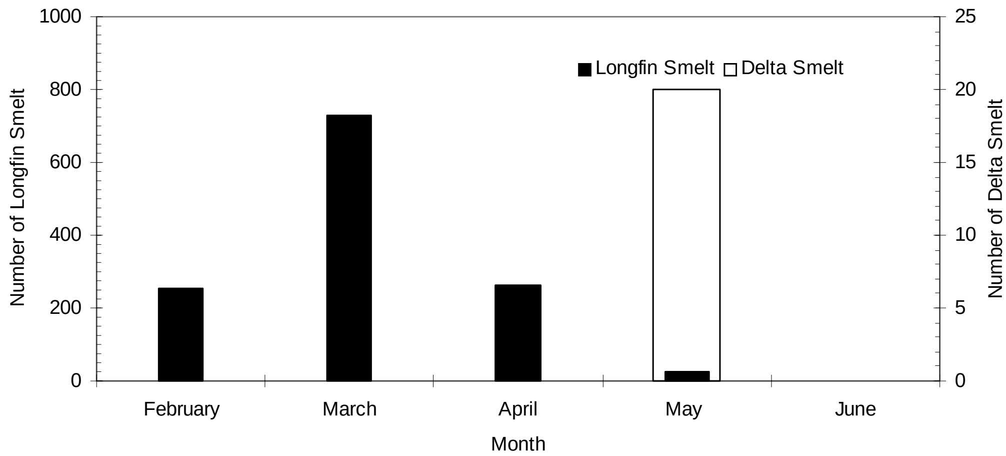

Figure 37 Number of larval osmerids captured each month from February through June 1997

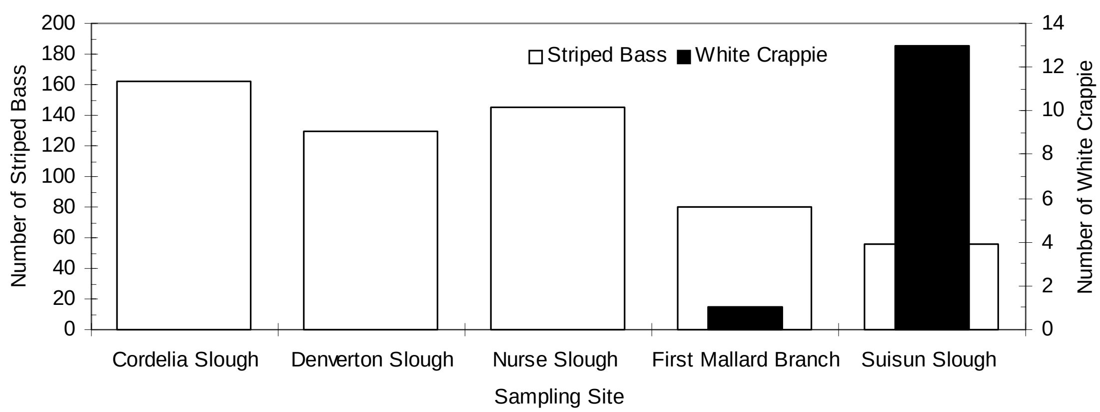

Figure 38 Number of larval striped bass and white crappie captured in each slough from February through June 1997

UC Davis biologists captured three other native and two introduced species during the 1997 sampling. The native species, in order of decreasing abundance, were threespine stickleback, Sacramento sucker, and Sacramento blackfish. The introduced species were inland silverside and carp. Pleuronectids were also captured but not identified to the species level. Most threespine sticklebacks were captured in February and in Cordelia Slough (Figures 42 and 43). The majority of Sacramento suckers were captured in April and in First Mallard Branch. Only one Sacramento blackfish was captured during the sampling. UC Davis researchers captured inland silversides in June and carp in April and May in Denverton Slough (Figure 44 and 45).

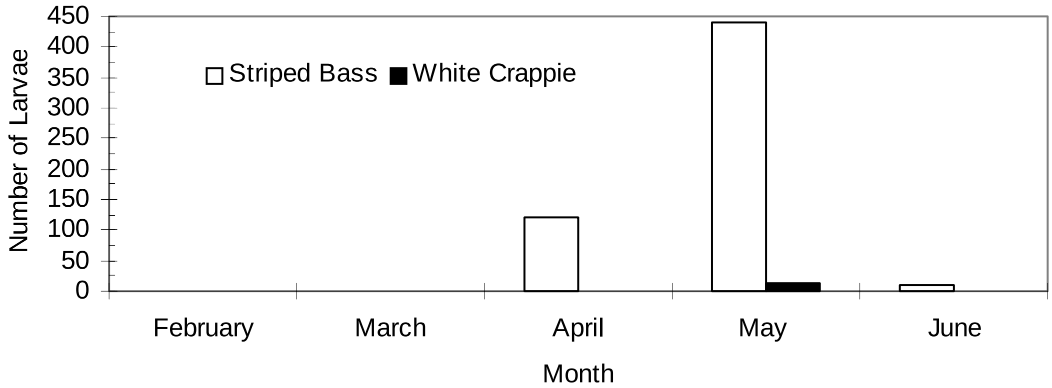

Figure 39 Number of larval striped bass and white crappie captured each month from February through June 1997

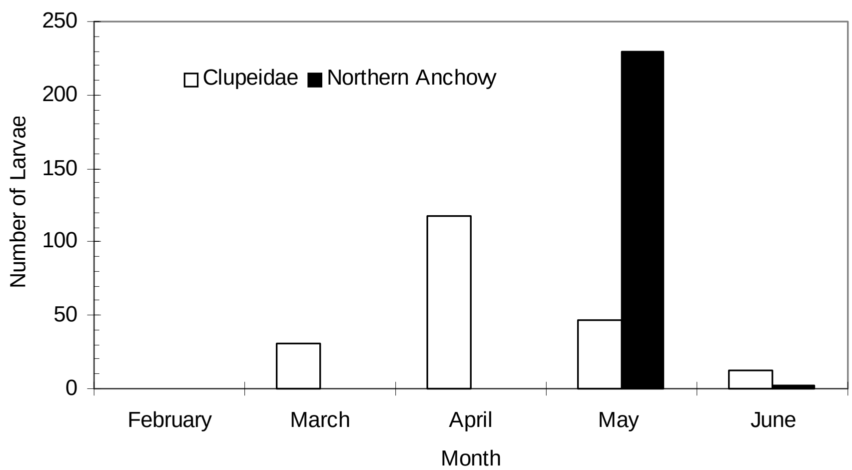

Figure 40 Number of larval clupeids and northern anchovy captured each month from February through June 1997

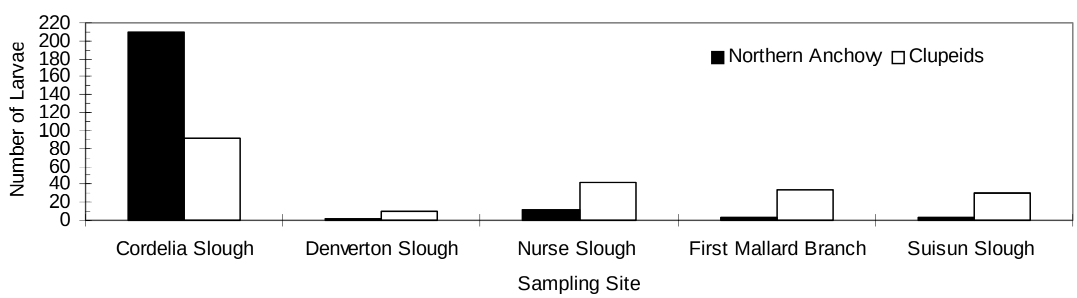

Figure 41 Number of larval clupeids and northern anchovy captured in each slough from February through June 1997

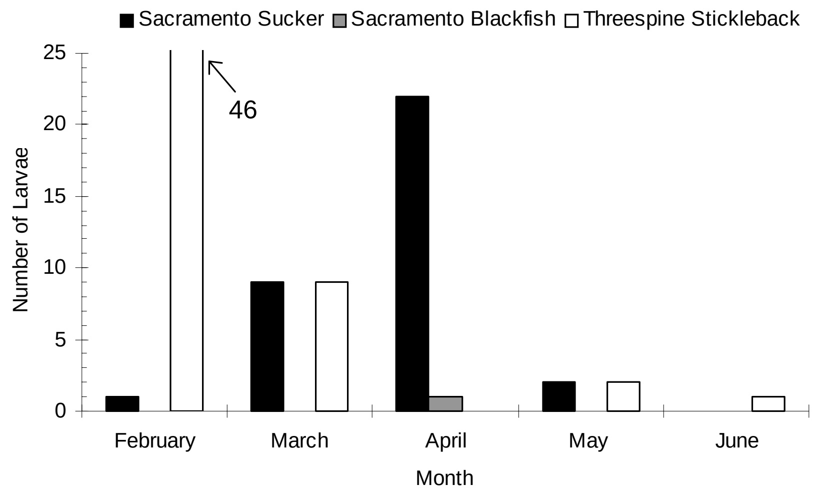

Figure 42 Number of larval Sacramento sucker, Sacramento blackfish, and threespine stickleback captured each month from February through June 1997

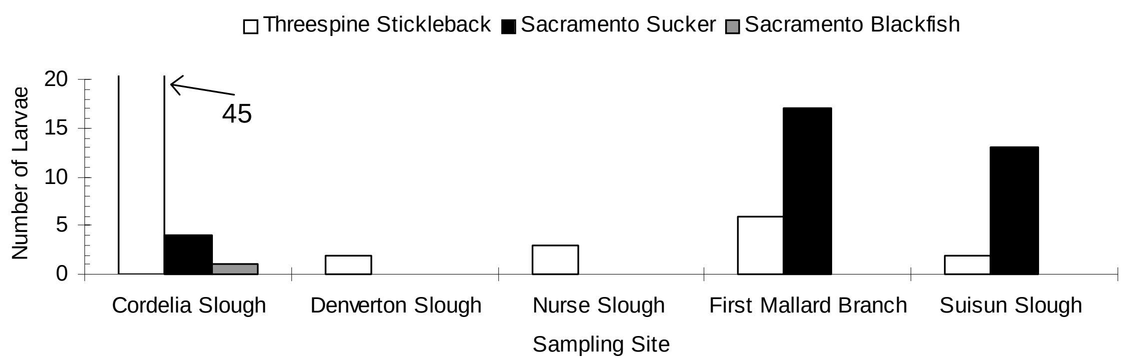

Figure 43 Number of larval Sacramento sucker, Sacramento blackfish, and threespine stickleback captured in each slough from February through June 1997

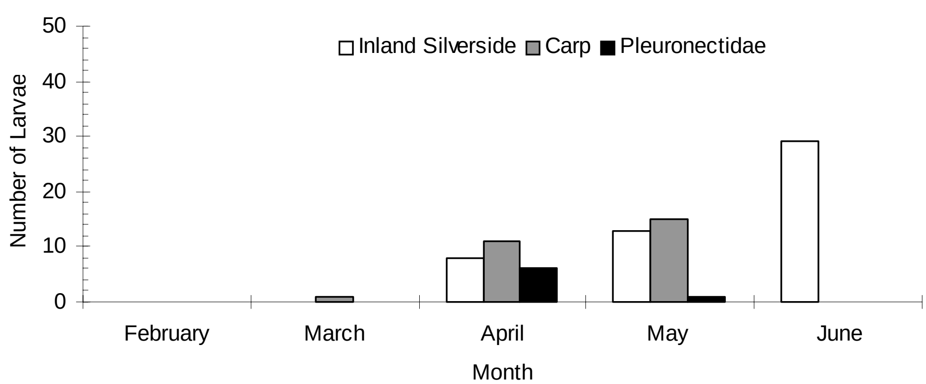

Figure 44 Number of larval inland silverside, carp, and pleuronectids captured each month from February through June 1997

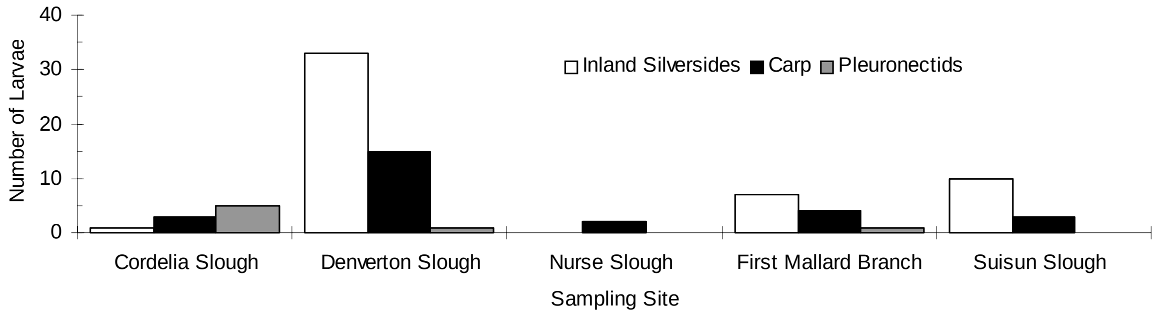

Figure 45 Number of larval inland silverside, carp, and pleuronectids captured in each slough from February through June 1997

Chapter 7
Effects on Adult Salmon

In 1993, DWR convened the SMSCG Steering Group, a technical advisory group of biologists from DWR, DFG, US Bureau of Reclamation, US Army Corps of Engineers, National Marine Fisheries Service, US Fish and Wildlife Service, and Suisun Resource Conservation District. The group is charged with recommending, designing, and reviewing monitoring studies and results to ensure DWR meets US Army Corps of Engineers permit requirements for SMSCG operations. Since 1993, the SMSCG Steering Group has focused on addressing potential effects of SMSCG operations on migratory fish, specifically adult chinook salmon. Adult salmon migration studies conducted in 1993 and 1994 in Montezuma Slough were initiated as part of this effort. In fall 1993, a pilot adult salmon migration study was completed, which was followed by a complementary tracking study in fall 1994. From the conclusions drawn from the 1993 and 1994 study results, the SMSCG Steering Group recommended that an evaluation of the studies be conducted based on a chinook salmon population level review rather than solely at the level of individual salmon.

The report, *Implications of the Delay at the Suisun Marsh Salinity Control Gates on Chinook Salmon Upstream Migrants* (DWR 1997b), is the outcome of the SMSCG Steering Group recommendation for a population level evaluation of the potential effects of SMSCG operations. The report focuses on winter-run and spring-run chinook salmon. Fall-run and late fall-run chinook salmon were included to provide a comprehensive picture of potential SMSCG effects on chinook salmon. DWR staff discussed what is currently understood about adult chinook salmon migration patterns and life history for the four races of salmon identified in the Sacramento River and San Joaquin River system, and how SMSCG operations may influence their migration patterns and survival.

DWR staff prepared the *Adult Chinook Salmon Passage Mitigation Report* (DWR 1997c) which discusses various measures to minimize delays at the SMSCG. The SMSCG Steering Group evaluated the measures based on their effects on salinity and their probability of increasing salmon passage. The group chose an option to create two 3-foot horizontal slots in the flashboards. Preliminary evaluations suggested that these slots might provide passage for adult salmon without significantly changing salinity levels in Suisun Marsh. DFG and DWR staff designed a three-year study to evaluate the effectiveness of the slots and resulting changes in salinity.

The first year of the study began in fall 1998. The following is a summary of the study design (Edwards and Fujimura 1998). There are two objectives: (1) to determine if the modification of the SMSCG flashboards results in a significant increase in adult chinook salmon passage rates when compared with full operation and (2) to determine if there is a significant difference in salmon passage rates when operation with the modified flashboards in place is compared to no operation. These objectives will be fulfilled by the following three study components:

- Measure and compare the passage rates, patterns and depths of adult chinook salmon migrating through the SMSCG under the following scenarios:

    1. Full operation: The standard SMSCG flashboards are in place, the gates are tidally operated and the boat lock is operated.

    2. No operation: The flashboards and gates are out of the water and the boat lock is operated.

3. Full operation with modified flashboards: The two 3-foot horizontal slots are in place in the flashboards, the gates are tidally operated, and the boat lock is operated.

4. Passage rate is calculated as the time between release after tagging to detection on the upstream side of the SMSCG.

- Determine if the mitigation measure resulted in a significant improvement in adult salmon passage rates.

- Compare results of this study with results from the 1993 and 1994 adult salmon passage studies.

The effectiveness of the modification will be determined by statistical analysis. Statistical tests will be used to determine the significance of the proportion of tagged fish that pass through the SMSCG and differences in mean fish passage times. An interim report is expected in July 1999. Eventually, fisheries and salinity data from all three years of the program will be evaluated by the SMSCG Steering Group to determine whether the modification is successful.

Chapter 8
Analysis of the Relationship Between Fish Abundance and Salinity in Suisun Marsh

Background

Studies have been conducted to determine the effect of SMSCG operations on salmonid migration, as well as fish predation in Suisun Marsh. One issue not evaluated until recently addresses whether the abundance of native marsh fish is affected by changes in salinity caused by SMSCG operations. This section discusses the results of an analysis used to assess whether juvenile, adult, and larval fish in the marsh could be affected positively or negatively by decreases in salinity in the marsh due to SMSCG operations.

Scientific literature indicates that critical periods exists for many spawning and larval fish between February and June, during which time many fish species native to the marsh may be sensitive to higher salinity levels (Wang 1986; Moyle 1976; Unger 1994; CUWA 1994; SFBAEWGP 1997). Thus, it is considered important to maintain low salinity conditions for spawning and larval rearing during this period to support native fish species in the marsh (personal communication with Dr. Peter Moyle and Mr. Randall Baxter, unreferenced, see “Notes”). The literature also indicates that adult and juvenile native fish found in the marsh have broad salinity tolerance ranges. This suggests that adult and juvenile fish would not be affected by changes in salinity during most of the year (Wang 1986; Moyle 1976; Unger 1994; CUWA 1994). However, it has also been hypothesized that increases in the relative abundance of introduced fish in the marsh may be linked to the frequency with which freshwater conditions prevail during fall due to SMSCG operations (Moyle and Herbold 1983, 1986). SMSCG operations decrease the natural variability of the salinity regime in the marsh. Moyle and Herbold (1986) have hypothesized that maintaining low salinities in the fall may help to establish freshwater, introduced resident species.

The following analysis could not address whether a relationship exists between low salinity conditions in the fall due to SMSCG operations and the increase in relative abundance of introduced species. However, the analysis is a first step in determining whether a relationship exists between channel water salinity and fish abundance in the marsh. Specifically, catch per unit effort[5] of select juvenile, adult, and larval fish species and corresponding channel water salinity data[6] were plotted to determine whether a relationship exists between them.

Scatter plots were used as a first-order data analysis to determine whether a correlation exists between fish abundance and salinity. If a correlation between the two variables exists, the array of data points in a scatter plot will show a pattern or trend. For example, if fish abundance were positively correlated with low salinity, then the scatter plot would show abundance increasing as salinity decreased. If there were no correlation between the variables then the data points would appear to be distributed randomly with respect to salinity. The greater the number of data points in the scatter plot, the more accurate the scatter plot is in terms of elucidating the relationship between the variables.

5. Catch per unit effort (CPUE) is defined here as the number of fish caught per trawl.
6. Channel water salinity data was obtained during the trawling or towing effort.

Juvenile and Adult Fish

The evaluation of the relationship between juvenile and adult fish and channel water salinity used fish species abundance and salinity data collected by the UC Davis Suisun Marsh Fisheries Sampling Program between 1979 and 1996. These data were obtained on monthly trawling events conducted in Boynton, Cutoff, Denverton, Goodyear, Peytonia, Nurse, Montezuma, Spring Branch, and Suisun sloughs. For each trawling event, a grab sample was taken to measure salinity and other chemical constituents. For a complete description of the methods used in the UC Davis Suisun Marsh Fisheries Sampling Program, see Matern and others 1998.

Fourteen fish species were selected for evaluation: nine native species and five introduced species (Table 13). Species selected are considered to be representative of the marsh community. The list includes fish that are resident, non-resident, or migratory, and that occupy a variety of marsh habitats. Though the primary aim was to determine the effect of SMSCG operations on native fish (as well as the recreationally important introduced fish, striped bass), other introduced species were included to assess whether native and introduced species respond differently to salinity levels.

The data were queried to obtain the number of a particular species caught in each trawl and the salinity at which the trawl occurred. No salinity data were obtained from trawling events for which the species in question was not caught. These data were used to generate scatter plots that show the relationship between channel water salinity and catch. Data were not separated by size class, thus the analysis does not differentiate between juvenile and adult fish.

Table 13 Fish species included in the analysis of juvenile and adult fish

Common Name	*Scientific Name*	*Origin*
Chinook salmon	*Oncorhynchus tshawytscha*	Native
Delta smelt	*Hypomesus transpacificus*	Native
Longfin smelt	*Spirinchus thaleichthys*	Native
Prickly sculpin	*Cottus asper*	Native
Sacramento sucker	*Catostomus occidentalis*	Native
Splittail	*Pogonichthys macrolepidotus*	Native
Starry flounder	*Platichthys stellatus*	Native
Threespine stickleback	*Gasterosteus aculeatus*	Native
Tule perch	*Hysterocarpus traski*	Native
Carp	*Cyprinus carpio*	Introduced
Shimofuri goby	*Tridentiger bifasciatus*	Introduced
Striped bass	*Morone saxatilis*	Introduced
Threadfin shad	*Dorosoma petenense*	Introduced
Yellowfin goby	*Acanthogobius flavimanus*	Introduced

Table 14 Optimal salinity ranges for different fish species at various life stages

Species and Life Stage	*Optimal Salinity Range*	*Source*
Chinook salmon		
juvenile, adult	≥0 ppt	CUWA 1994
Delta smelt		
rearing, pre-spawning	0 to 2 ppt; up to 14 ppt	SFBAEWGP 1997; DFG 1992
larvae, early juvenile	0.3 to 1.8 ppt	Unger 1994
juvenile	0.5 to 10 ppt	CUWA 1994
adult	0 to 10 ppt	CUWA 1994
Longfin smelt		
spawning	0 to 0.5 ppt	CUWA 1994
larvae, early juvenile	1.1 to 18.5 ppt	Unger 1994
adult	≥0 ppt	CUWA 1994
Prickly sculpin		
juveniles, adults	0 to 10 ppt	SFBAEWGP 1997
Splittail		
spawning, eggs, larvae	0 to 5 ppt	CUWA 1994
adults	0 to 10 ppt; up to 18 ppt	Sommer and others, forthcoming
Striped bass		
spawning	optimal at <1 ppt	Moyle 1976
larvae	peak abundance 0 to 2 ppt	SFBAEWGP 1997
juvenile	≥0 ppt	CUWA 1994
adults	≥0 ppt	CUWA 1994
Starry flounder		
young of the year	0.1 to 19.7 ppt	Unger 1994
Tule perch		
breeding, juveniles	0 to 0.5 ppt	CUWA 1994
adults	0 to 5 ppt	CUWA 1994

Grab sample salinity data from all the trawling events in the nine sloughs over the past 17 years were divided into wet, critical, and dry water year types (using the 1995 Water Quality Control Plan Order WR 95-6 Sacramento Valley 40-30-30 Water Year Hydrologic Classification). The greatest salinities reached during the sampling periods and the frequency with which salinity fell into specific intervals were determined. The intervals were chosen to reflect optimal salinities for spawning and rearing (Table 14). By dividing the data into intervals, the availability of optimal salinity conditions for spawning and rearing could be assessed. Although it would be instructive to compare salinity levels of different water year types during conditions of operation and non-operation, not enough data exist to make a valid comparison.

Table 15 Frequency of occurrence for specific salinity ranges in Suisun Marsh during wet years 1982, 1983, 1984, 1986, 1995, and 1996. Based on data from nine sloughs.

Units	*Salinity Range*								
ppt	0 - 0.5	0.6 - 1.8	1.9 - 2.5	2.6 - 5.0	5.1 - 10	10.1 - 14	14.1 - 18	18.1 - 20	
mS/cm	0 - 0.8	0.9 - 2.8	2.9 - 3.9	4.0 - 7.8	7.9 - 15.6	15.7 - 21.9	22 - 28.1	28.2 - 31.2	
Month	*Frequency of Occurrence (%)*								*Total Trawls*
Jan	50.5	28.6	3.3	14.3	3.3	0.0	0.0	0.0	91
Feb	58.3	30.6	8.3	2.8	0.0	0.0	0.0	0.0	108
Mar	60.0	32.4	4.8	2.9	0.0	0.0	0.0	0.0	105
Apr	48.9	44.3	4.5	2.3	0.0	0.0	0.0	0.0	88
May	34.4	53.3	2.2	8.9	1.1	0.0	0.0	0.0	90
Jun	51.0	23.5	6.9	10.8	7.8	0.0	0.0	0.0	102
Jul	42.0	25.9	9.9	16.0	4.9	1.2	0.0	0.0	81
Aug	26.7	29.1	9.3	29.1	5.8	0.0	0.0	0.0	86
Sep	14.0	23.0	22.0	34.0	7.0	0.0	0.0	0.0	100
Oct	22.8	32.7	4.0	9.9	28.7	2.0	0.0	0.0	101
Nov	18.9	17.1	3.6	17.1	33.3	9.9	0.0	0.0	111
Dec	17.6	30.6	10.6	23.5	17.6	0.0	0.0	0.0	85

Results

Examination of the UC Davis grab sample salinity data indicates that, for the period of study, salinities rarely exceeded concentrations greater than 14 ppt (Tables 15 through 17). During the six wet years studied, salinity was never measured at concentrations greater than 14 ppt. During the five critical years studied, salinity fell into the 10 to 14 ppt range 10% to 22% of the time from June through January, and was greater than 14 ppt only 4% of the time. During the four dry years studied, salinity reached the 10 to 14 ppt range 3% to 12% of the time during June through September. However, it was never measured at concentrations above 14 ppt during these dry years. These data suggest that fish were rarely caught at salinities greater than 14 ppt because salinity in the areas sampled rarely exceeded this concentration (Figures 46 through 59).

Table 16 Frequency of occurrence for specific salinity ranges in Suisun Marsh during critical years 1988, 1990, 1991, 1992, and 1994. Based on data from nine sloughs.

Units	*Salinity Range*								
ppt	0 - 0.5	0.6 - 1.8	1.9 - 2.5	2.6 - 5.0	5.1 - 10	10.1 - 14	14.1 - 18	18.1 - 20	
mS/cm	0 - 0.8	0.9 - 2.8	2.9 - 3.9	4.0 - 7.8	7.9 - 15.6	15.7 - 21.9	22 - 28.1	28.2 - 31.2	
Month	*Frequency of Occurrence (%)*								*Total Trawls*
Jan	2.3	12.8	16.3	22.1	34.9	11.6	0.0	0.0	86
Feb	0.0	16.7	11.5	38.5	32.1	1.3	0.0	0.0	78
Mar	6.8	20.5	14.8	34.1	23.9	0.0	0.0	0.0	88
Apr	3.5	20.9	25.6	41.9	8.1	0.0	0.0	0.0	86
May	0.0	15.7	9.6	45.8	28.9	0.0	0.0	0.0	83
Jun	2.9	4.3	4.3	34.3	44.3	10.0	0.0	0.0	70
Jul	0.0	2.4	4.7	21.2	55.3	16.5	0.0	0.0	85
Aug	0.0	0.0	1.2	18.8	61.2	16.5	1.2	1.2	85
Sep	0.0	1.2	1.2	22.6	56.0	19.0	0.0	0.0	84
Oct	0.0	0.0	2.0	22.4	53.1	22.4	0.0	0.0	49
Nov	0.0	1.4	1.4	23.6	50.0	22.2	1.4	0.0	72
Dec	0.0	3.7	3.7	20.7	59.8	12.2	0.0	0.0	82

Table 17 Frequency of occurrence for specific salinity ranges in Suisun Marsh during dry years 1981, 1985, 1987, and 1989. Based on data from nine sloughs.

Units	*Salinity Range*								
ppt	0 - 0.5	0.6 - 1.8	1.9 - 2.5	2.6 - 5.0	5.1 - 10	10.1 - 14	14.1 - 18	18.1 - 20	
mS/cm	0 - 0.8	0.9 - 2.8	2.9 - 3.9	4.0 - 7.8	7.9 - 15.6	15.7 - 21.9	22 - 28.1	28.2 - 31.2	
Month	*Frequency of Occurrence (%)*								*Total Trawls*
Jan	0.0	2.3	11.4	54.5	31.8	0.0	0.0	0.0	44
Feb	0.0	27.6	24.1	43.7	4.6	0.0	0.0	0.0	87
Mar	11.7	30.9	23.4	28.7	4.3	1.1	0.0	0.0	94
Apr	5.1	29.3	31.3	26.3	8.1	0.0	0.0	0.0	99
May	0.0	17.8	22.2	45.6	14.4	0.0	0.0	0.0	90
Jun	0.0	7.7	11.5	38.5	32.7	9.6	0.0	0.0	52
Jul	0.0	8.6	4.9	28.4	55.6	2.5	0.0	0.0	81
Aug	0.0	1.4	1.4	16.4	75.3	5.5	0.0	0.0	73
Sep	0.0	1.4	1.4	10.8	74.3	12.2	0.0	0.0	74
Oct	0.0	4.9	2.4	90.2	2.4	0.0	0.0	0.0	41
Nov	1.3	8.9	5.1	67.1	17.7	0.0	0.0	0.0	79
Dec	1.1	3.4	10.1	57.3	28.1	0.0	0.0	0.0	89

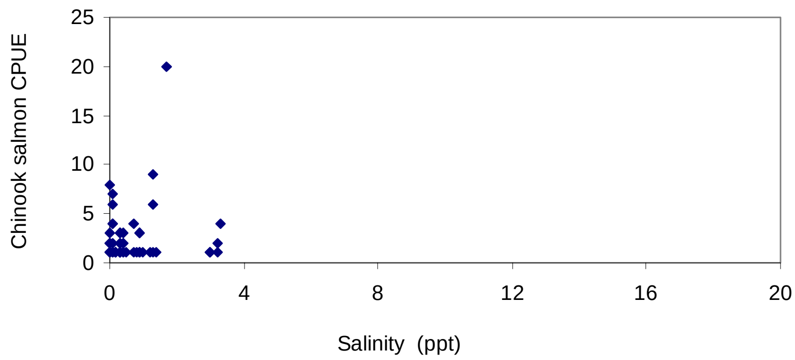

Figure 46 Chinook salmon catch versus salinity. Based on 62 data points.

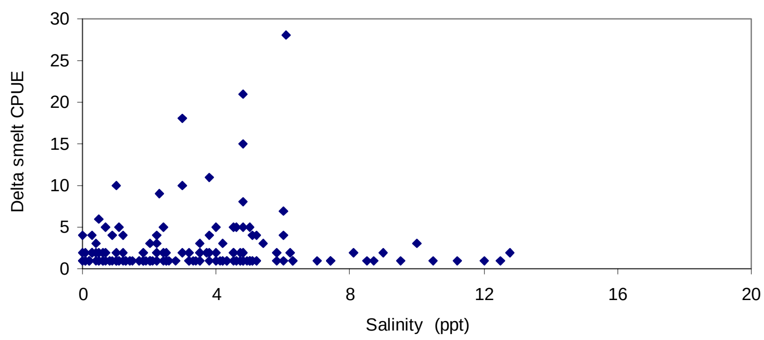

Figure 47 Delta smelt catch versus salinity. Based on 179 data points.

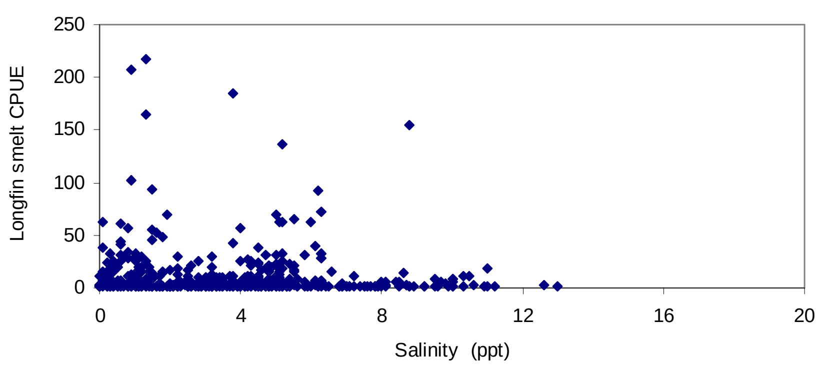

Figure 48 Longfin smelt catch versus salinity. Based on 530 data points.

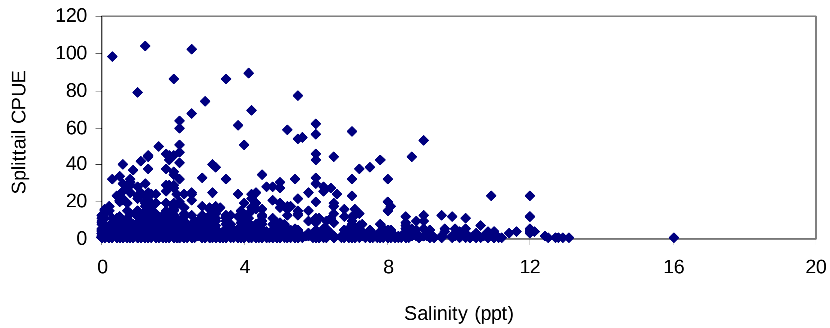

Figure 49 Splittail catch versus salinity. Based on 1,500 data points.

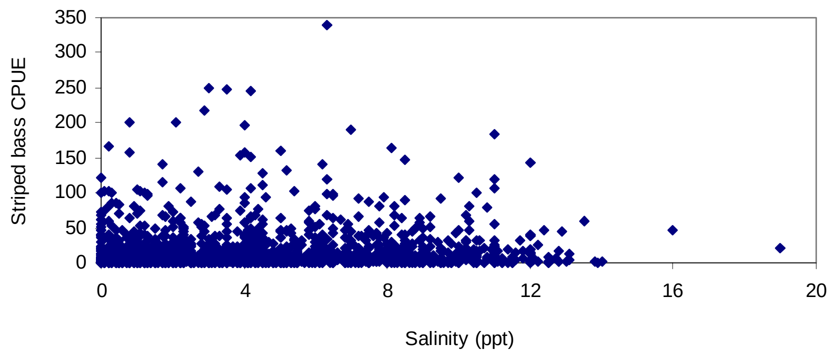

Figure 50 Striped bass catch versus salinity. Based on 2,431 data points.

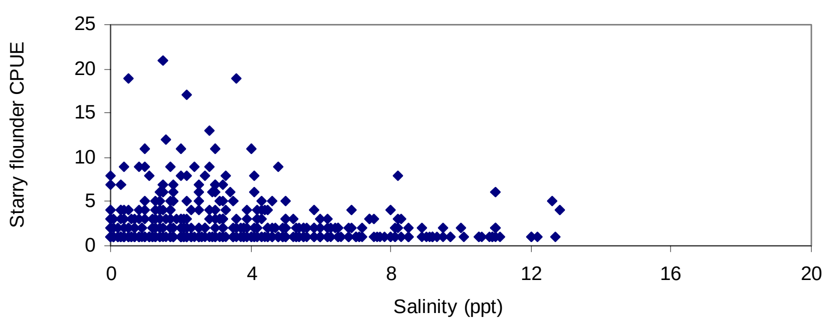

Figure 51 Starry flounder catch versus salinity. Based on 476 data points.

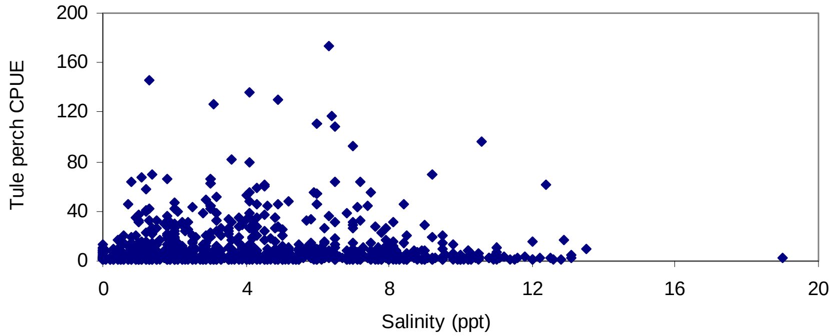

Figure 52 Tule perch catch versus salinity. Based on 1,113 data points.

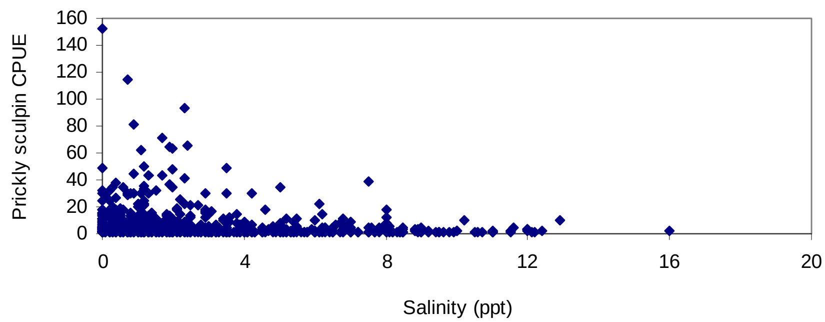

Figure 53 Prickly sculpin catch versus salinity. Based on 1,038 data points.

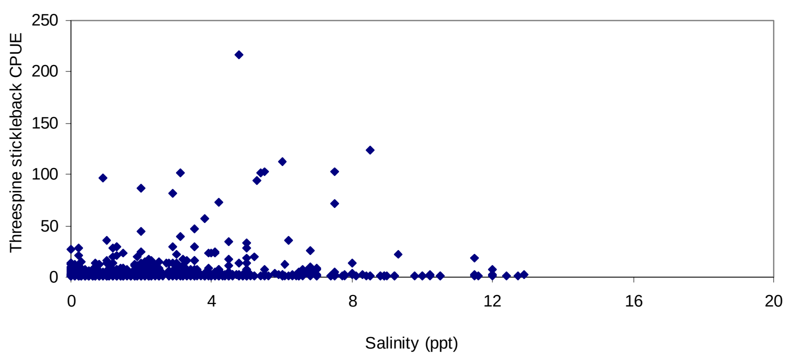

Figure 54 Threespine stickleback catch versus salinity. Based on 855 data points.

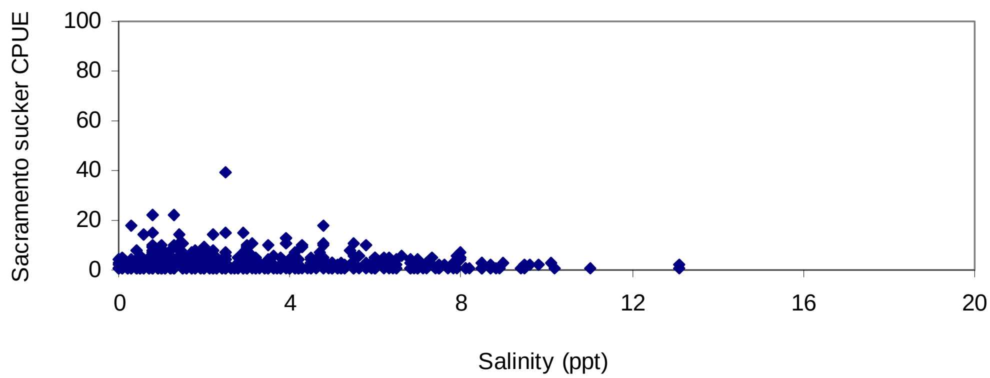

Figure 55 Sacramento sucker catch versus salinity. Based on 752 data points.

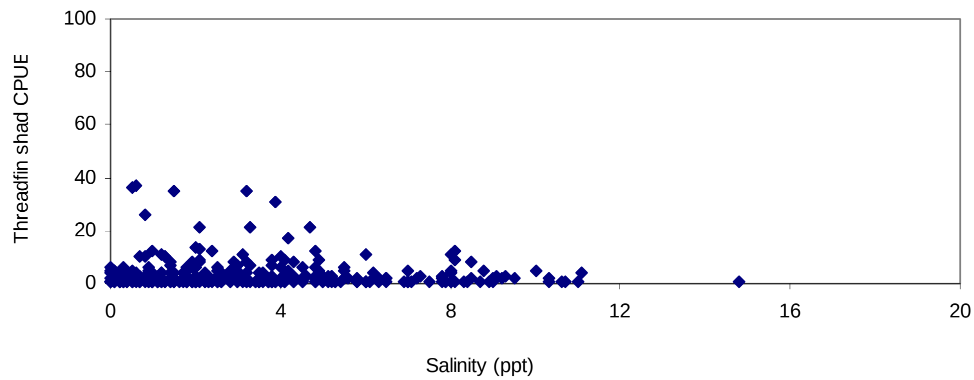

Figure 56 Threadfin shad catch versus salinity. Based on 340 data points.

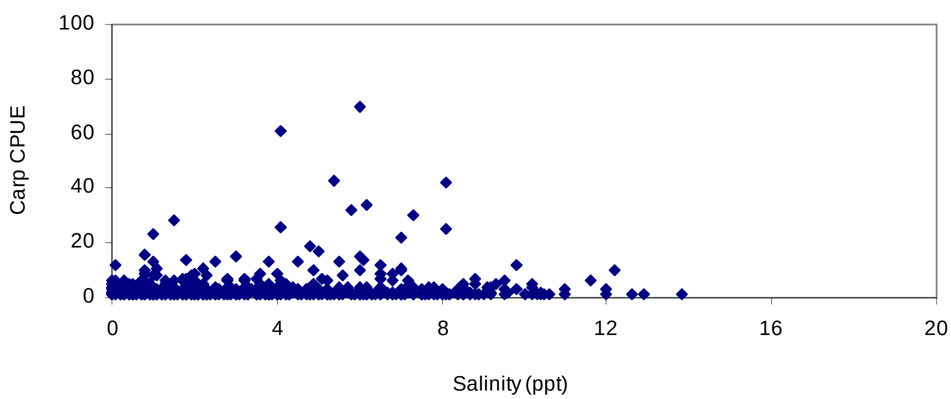

Figure 57 Carp catch versus salinity. Based on 871 data points.

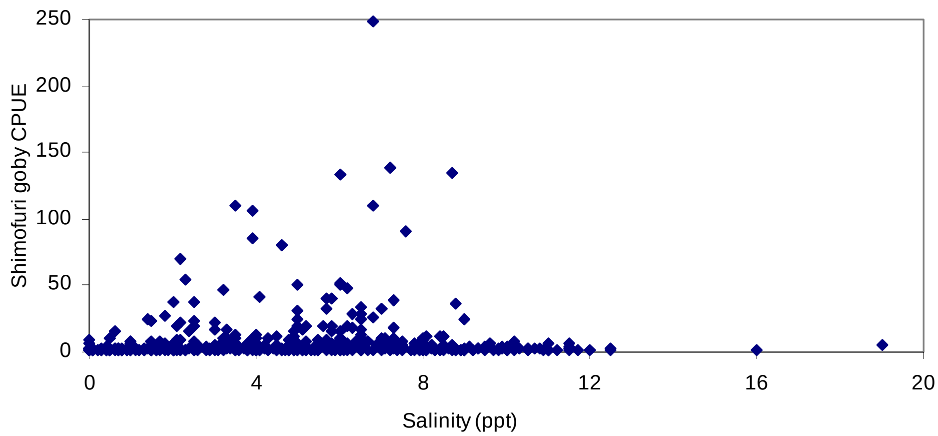

Figure 58 Shimofuri goby catch versus salinity. Based on 554 data points.

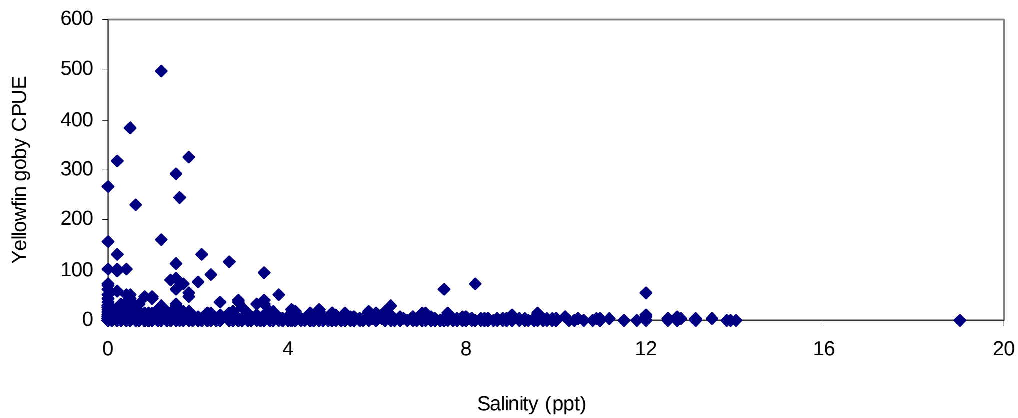

Figure 59 Yellowfin goby catch versus salinity. Based on 1,244 data points.

As indicated in Table 14, optimal salinity for spawning (or mating) and rearing is low, for fish such as longfin smelt, tule perch, striped bass, and delta smelt. For example, optimal salinity for longfin smelt spawning is 0 to 0.5 ppt from December through June. Table 15 indicates that optimal salinity conditions for longfin smelt spawning during the six wet years studied occurred with the lowest frequency in December (18% of the time) and highest in March (approximately 60% of the time). Thus, optimal salinity conditions for longfin smelt spawning during the six wet years occurred between 18% to 60% of the time. During the five critical years, optimal conditions for longfin smelt spawning occurred approximately 0% to 7% of the time (see Table 16), and during the four dry years, 0% to 12% of the time (see Table 17). For delta smelt, optimal salinity conditions for spawning and rearing (0 to 2 ppt from February through June) occurred 75% to 93% of the time in the wet years (see Table 15), 7% to 27% during the critical years (see Table 16), and 8% to 43% during the dry years (see Table 17)[7]. Not enough data exist from this data set to compare salinity levels with and without SMSCG operations. However, while these calculations are simple

7. These calculations were based on adding together the percentages for the first two salinity intervals (0 to 0.05 and 0.6 to 1.8) for each of the critical months of February through June. Thus, in February, salinity was approximately 0 to 2 ppt 89% of the time (58.3% + 30.6%), while in March it was in that interval 92% of the time (60% + 32.4%).

approximations, they suggest that optimal salinities for spawning and rearing occur much less frequently during dry and critical years than during wet years. SMSCG operations during dry and critical years may benefit certain marsh fish by lowering salinities during critical spawning and rearing months.

Table 18 Fish species included in the analysis of larval fish

Common Name	*Scientific Name*	*Origin*
Delta smelt	*Hypomesus transpacificus*	Native
Longfin smelt	*Spirinchus thaleichthys*	Native
Longjaw mudsucker	*Gillichthys mirabilis*	Native
Prickly sculpin	*Cottus asper*	Native
Splittail	*Pogonichthys macrolepidotus*	Native
Staghorn sculpin	*Leptocottus armatus*	Native
Starry flounder	*Platichthys stellatus*	Native
Striped bass	*Morone saxatilis*	Introduced
Shimofuri goby	*Tridentiger bifasciatus*	Introduced
Yellowfin goby	*Acanthogobius flavimanus*	Introduced

The scatter plots in Figures 46 through 59 suggest there is no clear correlation between channel water salinity and juvenile and adult fish abundance for any of the species evaluated. (Please note the variable scale on the y-axis.) The apparently random scatter of the data points between zero and approximately 12 ppt (19 mS/cm) suggests that abundances of these fish were not affected by channel water salinity within this range of salinity. This is consistent with the literature, which indicates that juvenile and adult fish of these species have broad salinity tolerance levels (Wang 1986; Moyle 1976; Unger 1994; CUWA 1994). For chinook salmon, the data points are clustered between 0 and 4 ppt, which is not reflective of the wide salinity tolerance range identified for juveniles and adults of this species (0 to 32 ppt, CUWA 1994). The scatter plot may not be representative simply because it is based on a small number of data points (62). Also, trawling may not be the most effective method for sampling juvenile chinook salmon.

Although scatter plots revealed no relationship between channel water salinity and adult and juvenile abundance, no conclusions can be drawn regarding the effect of fall SMSCG operations on the relative abundance of native and introduced fish species in the marsh. Future research should determine if maintaining low salinity conditions in the marsh or allowing greater variability in the salinity regime helps to establish introduced resident species in the marsh.

Larval Fish

Data obtained from the UC Davis Suisun Marsh Larval Fish Survey was used to evaluate the relationship between larval fish and channel water salinity. This survey began in 1994, when sampling was conducted weekly from mid-April through mid-June. Since that time, sampling has been conducted weekly every year from early February through June. Larvae are collected with a modified plankton sled from Spring Branch, Suisun, Cordelia, Nurse, and Denverton sloughs. For each sampling event, a grab sample was taken to measure salinity and other chemical parameters. A complete description of the methods is available in Matern and others 1998.

As with the adult analysis, the larval data were queried to obtain the number of a particular taxon (family or species when available) caught in each tow and the salinity at which the tow occurred. Table 18 lists all species that were included in the analysis. (All native species captured in the larval survey are included in the list.) No salinity data were obtained from towing events for which the species in question was not caught. These data were used to make scatter plots which show the relationship between channel water salinity and larval catch (Figures 60 through 66; note variable scale on y-axis).

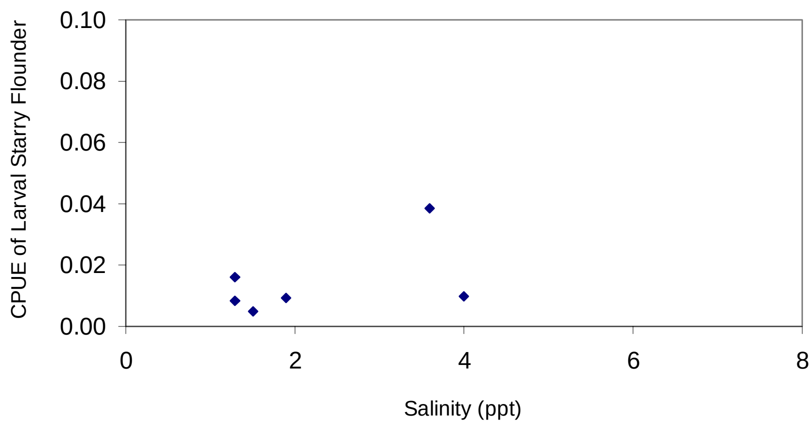

Figure 60 Larval starry flounder abundance versus salinity from 1994 to 1998. Based on six data points. No starry flounder were caught in 1995 or 1998.

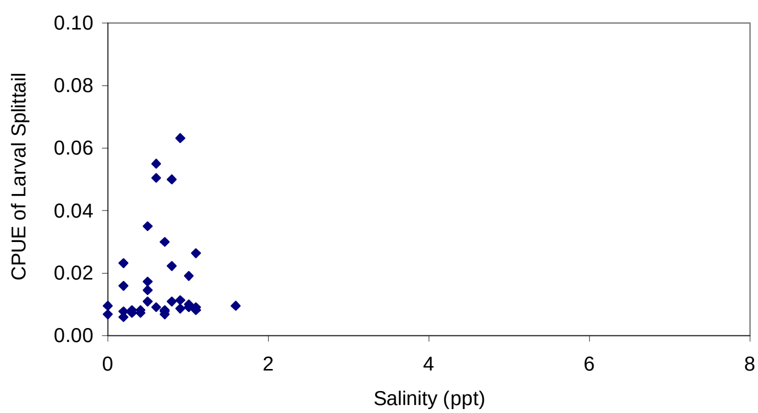

Figure 61 Larval splittail abundance versus salinity from 1994 to 1998. Based on 36 data points. No splittail were caught in 1994 or 1997. The five highest CPUE values occurred in April 1995.

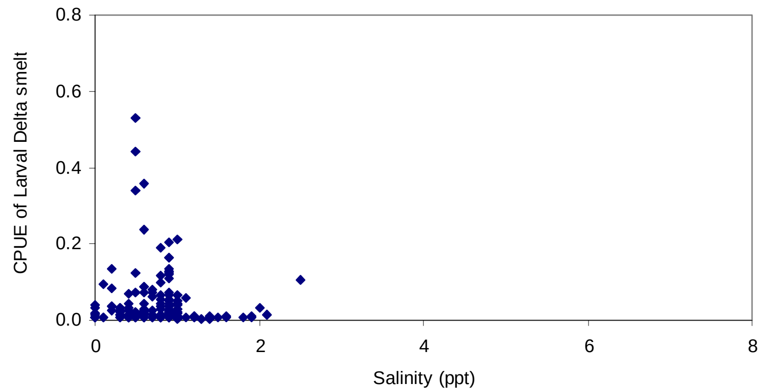

Figure 62 Larval delta smelt abundance versus salinity from 1994 to 1998. Based on 180 data points. The four highest CPUE values occurred on 10 May 1996.

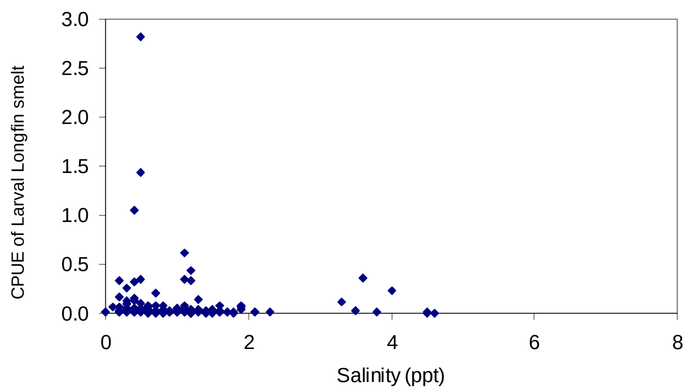

Figure 63 Larval longfin smelt abundance versus salinity from 1994 to 1998. Based on 190 data points. All eight CPUE values greater than 100 occurred in 1997.

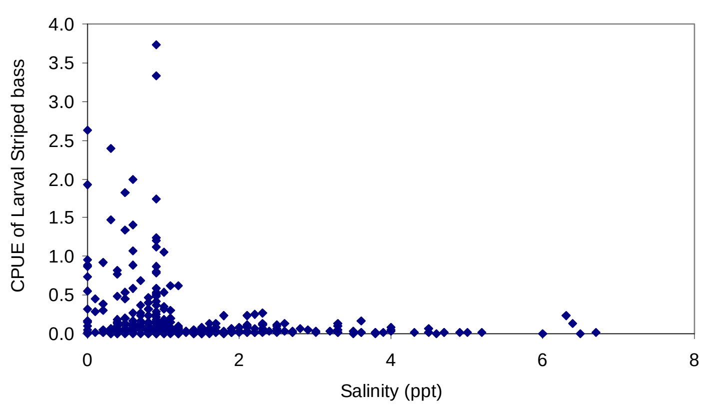

Figure 64 Larval striped bass abundance versus salinity from 1994 to 1998. Based on 375 data points. All eight CPUE values greater than 1.5 occurred in June 1995 and May and June 1996.

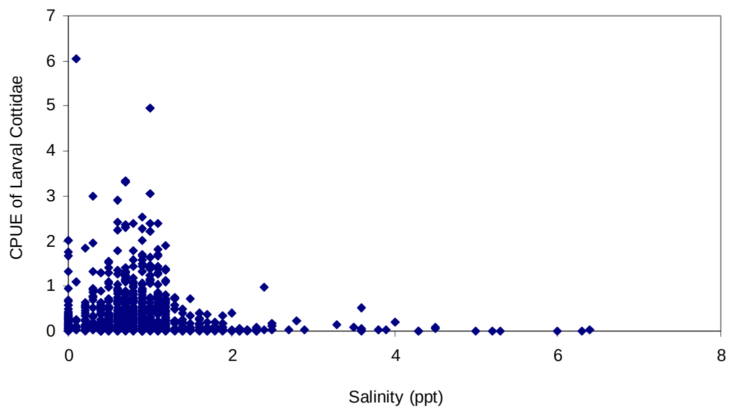

Figure 65 Larval Cottidae abundance versus salinity from 1994 to 1998. Based on 923 data points. In 1994 and 1995, both prickly sculpin and staghorn sculpin were caught. Since 1996, only prickly sculpin have been caught. Four of the five highest CPUE values were measured in 1995, while one was measured in 1998.

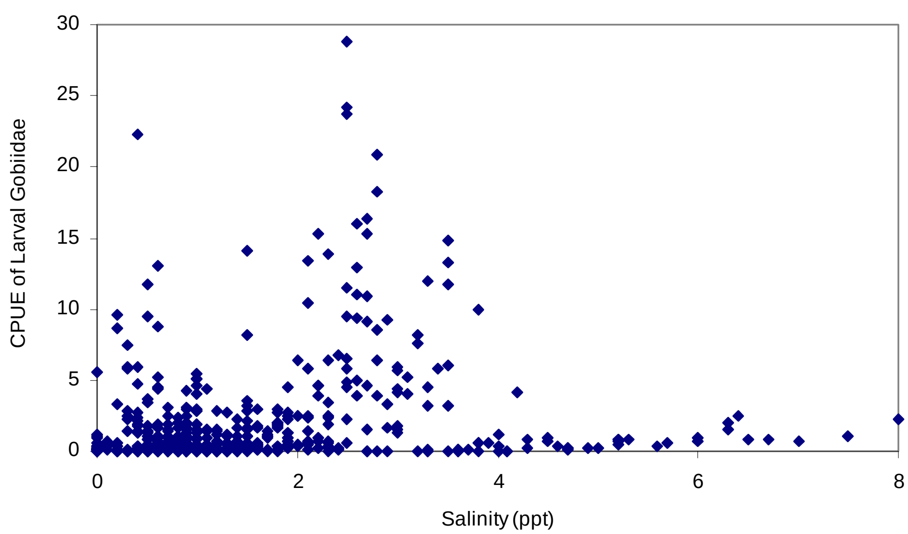

Figure 66 Larval Gobiidae abundance versus salinity from 1994 to 1998. Based on 614 data points. Yellowfin and shimofuri goby were caught in all five years, while longjaw mudsucker were caught only in 1994 and 1995.

Table 19 Frequency of occurrence for particular salinity ranges in Suisun Marsh during larval sampling from February through June, 1994 to 1998. Based on data from five sloughs.

Units	*Salinity Range*				
ppt	0 - 0.5	0.6 - 1.8	1.9 - 2.5	2.6 - 5.0	5.1 - 8.0
mS/cm	0 - 0.8	0.9 - 2.8	2.9 - 3.9	4.0 - 7.8	7.9 - 15.6
Month	*Frequency of Occurrence (%)*				
February	37.5	62.5	0.0	0.0	0.0
March	35.6	63.7	0.7	0.0	0.0
April	17.6	75.3	1.4	5.4	0.4
May	16.7	55.3	17.3	8.7	2.0
June	30.9	30.9	10.7	20.8	6.7

Grab sample salinity data from all larval sampling events conducted between 1994 and 1998 were divided into intervals to determine the ranges of salinity values in the marsh during larval sampling. Since only five years of data were available, the data were not divided into water year types.

Results

The five years of larval sampling data indicate that salinity ranged from 0 to 8 ppt from February through June (Table 19). Salinity was less than or equal to 1.8 ppt nearly 100% of the time in February and March, 93% of the time in April, 72% of the time in May, and 62% of the time in June. Thus, salinity levels were low enough to support larval rearing. This is not surprising since four of the five years sampled were wet years.

The scatter plots suggest that there was no clear correlation between channel water salinity and larval fish abundance. While in most cases the data points were clustered in the 0 to 2 ppt range, this may primarily reflect the fact that salinity occurred in this range a high percentage of the time. As might be predicted from the salinity tolerance levels identified in the literature, delta smelt larvae were rarely captured in waters greater than 2 ppt. This may confirm the importance of low salinities for larval rearing of fish such as delta smelt. Longfin smelt larvae were not often captured at salinities higher than 2 ppt either, although the literature indicates that they can tolerate salinities up to 18.5 ppt (Unger 1994). These two fish contrast with Gobiidae, which had high CPUEs at lower salinity levels and relatively high CPUEs at salinities above 4 ppt as well.

Though limited, these data may suggest that larval abundances of delta smelt, longfin smelt, splittail, striped bass, prickly sculpin, and staghorn sculpin tend to be higher when channel water salinities are less than 2 ppt. However, not enough data exist on the abundance of larval fish during dry and critical years to make any conclusions as to the relationship between salinity and abundance of these larval fish.

Conclusion

The purpose of this analysis was to examine whether SMSCG operations may positively or negatively affect the abundance of juvenile, adult, and larval fish in the marsh. This examination approached the question indirectly by determining whether there was a correlation between salinity and abundance of fish in the marsh. Scatter plots revealed no direct relationship between adult and juvenile fish abundance and salinity. These results agree with findings from the literature, which indicate that most species of fish found in Suisun Marsh have broad salinity tolerance levels at the adult and juvenile stages. Examination of the corresponding salinity data indicated that optimal salinity for spawning occurs a relatively high percentage of the time during wet years, but much less often during dry and critical years. This suggests SMSCG operations may play an important role in freshening the marsh for spawning during such years.

No clear correlation was evident from the comparison of larval abundance and channel water salinity, based on five years of data. While most of the larval catches occurred in the 0 to 2 ppt range, this may primarily reflect the fact that four of the five years sampled were wet years, and thus, salinity during the months of sampling was most frequently in this low range. However, the data may suggest a relationship between low channel water salinity (0 to 2 ppt) and high larval abundance. Data on larval abundances during dry and critical years are needed to determine whether such a relationship exists.

This examination suggests decreases in channel water salinity from February through June may benefit native fish species during dry and critical years by providing optimal salinity conditions for spawning and rearing of larval fish. More research is needed to assess the effect of fall SMSCG operations and subsequent decreases in channel water salinity on the establishment of introduced resident fish.

References

Alpine AE and JE Cloern. 1992. Trophic dynamic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography* 37(5):946–55.

[CUWA] California Urban Water Agencies. 1994. Evaluation of potential effects of the proposed EPA salinity standard on the biological resources of the San Francisco Bay/Sacramento-San Joaquin Estuary (Draft). Prepared by R2 Resource Consultants, Inc. for The California Urban Water Agencies. Sacramento, CA, March 7, 1994. Reference No. 5. 65 p. + appendices.

[DWR] California Department of Water Resources, Central District. 1994. Plan of Protection for the Suisun Marsh including Environmental Impact Report. Sacramento (CA): California Department of Water Resources. 176 p + appendices.

[DWR] California Department of Water Resources. 1997a. Suisun Marsh Salinity Control Gates Fisheries Monitoring, 1995 Annual Report. Sacramento (CA): California Department of Water Resources. 59 p.

[DWR] California Department of Water Resources. 1997b. Implications of the Delay at the Suisun Marsh Salinity Control Gates on Chinook Salmon Upstream Migration. Sacramento (CA): California Department of Water Resources. 44 p.

[DWR] California Department of Water Resources. 1997c. Adult Chinook Salmon Passage Mitigation Report. Sacramento (CA): California Department of Water Resources. 42 p.

Edwards GW and R Fujimura. 1998. Final Quality Assurance Project Plan for the 1998 Evaluation of the Modification of the Suisun Marsh Salinity Control Gates on Adult Fall-Run Chinook Salmon Passage. Stockton (CA): California Department of Fish and Game. 58 p.

Foss SF and LW Miller. 1996. Tow-net survey: 1995 Young-of-the-year striped bass index. *IEP Newsletter* Summer 1996:11–5.

Herbold B, AD Jassby, and PB Moyle. 1992. San Francisco Estuary Project Status and Trends Report on Aquatic Resources in the San Francisco Estuary. Prepared by University of California, Davis, for the San Francisco Estuary Project, U.S. Environmental Protection Agency. Oakland (CA): San Francisco Estuary Project. 257 p. + appendices.

Heubach W. 1969. *Neomysis awatschensis* in the Sacramento-San Joaquin River Estuary. *Limnology and Oceanography* 14(4):533–46.

Matern S and PB Moyle. 1994. Trends in Fish Populations of Suisun Marsh, January 1992 - December 1993. Annual Report for Contract B-59287. Sacramento (CA): California Department of Water Resources. 18 p.

Matern S, L Meng, and PB Moyle. 1995. Trends in Fish Populations of Suisun Marsh, January 1994 - December 1994. Annual Report for Contract B-59636. Sacramento (CA): California Department of Water Resources. 36 p.

Matern S, L Meng, and PB Moyle. 1997. Trends in Fish Populations of Suisun Marsh, January 1996 - December 1996. Annual Report for Contract 80900. Sacramento (CA): California Department of Water Resources. 52 p.

Matern S, L Meng, and PB Moyle. 1998. Trends in Fish Populations of Suisun Marsh, January 1997 - December 1997. Annual Report for Contract 98-0330-B-81183. Sacramento (CA): California Department of Water Resources. 49 p.

Monroe MW and J Kelly. 1992. San Francisco Estuary Project State of the Estuary: A Report on Conditions and Problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. Prepared under Cooperative Agreement CE-009486-02 with the U.S. Environmental Protection Agency. Oakland (CA): San Francisco Estuary Project. 270 p.

Moyle P. 1976. Inland fishes of California. Berkeley (CA): University of California Press. 405 p.

Moyle PB and B Herbold. 1983. A Survey of the Fishes of Suisun Marsh: Five Year Progress Report. Davis (CA): Department of Wildlife and Fisheries Biology, University of California, Davis. 10 p.

Moyle PB and B Herbold. 1986. Patterns in the Distribution and Abundance of Suisun Marsh Fishes: 1979 - 1986. Davis (CA): Department of Wildlife and Fisheries Biology, University of California, Davis.

National Oceanic Service, US Department of Commerce, National Oceanic and Atmospheric Administration, and US Naval Observatory. 1996. 1997 Tidelog: Northern California. Bolinas (CA): Pacific Publishers. unnumbered.

Obrebski S, JJ Orsi, and W Kimmerer. 1992. Long-Term Trends in Zooplankton Distribution and Abundance in the Sacramento-San Joaquin Estuary. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 32. Sacramento (CA): California Department of Water Resources. 42 p.

Orsi JJ and LW Mecum. 1994. Decline of the opossum shrimp, *Neomysis mercedis*. *IEP Newsletter* Autumn 1994:10–1.

Orsi JJ. 1997. Relative abundance and some aspects of the biology of native and introduced mysid shrimp in Suisun Bay and the Delta. *IEP Newsletter* 10(3):13–4.

Raquel P. 1988. Striped Bass Egg and Larval Monitoring near the Montezuma Slough Salinity Control Structure, 1987. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 16. Sacramento (CA): California Department of Water Resources. 7 p.

[SFBAEWGP] San Francisco Bay Area Wetland Ecosystem Goals Project. September 1997. Draft species narratives for fish and macroinvertebrates [unpublished draft]. **Available from?**

Sommer TR, R Baxter and B Herbold. Forthcoming. The resilience of splittail in the Sacramento-San Joaquin Estuary. *Transactions of the American Fisheries Society.*

Spaar SA. 1988. Suisun Marsh Salinity Control Gate Pre-project Fishery Resource Evaluation. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Technical Report 17. Sacramento (CA): California Department of Water Resources. 52 p.

Spaar SA. 1992. Suisun Marsh Salinity Control Gates, Fishery Related Studies, 1992 Annual Report. Sacramento (CA): California Department of Water Resources. 44 p.

Unger PA. 1994. Quantifying salinity habitat of estuarine species. *IEP Newsletter* Autumn 1994:7–10.

Wang J. 1986. Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 9. Sacramento (CA): California Department of Water Resources.

Notes

Foss, Steve (California Department of Fish and Game, Stockton). E-mail communication with author on 4 March 1999.

Mecum, Lee (California Department of Fish and Game, Stockton). Fax communication with author on 28 January 1995.

Mecum, Lee (California Department of Fish and Game, Stockton). Personal conversation with author in December 1997.

Moyle, Peter (University of California, Davis). E-mail communication with author on 11 April 1998.

Baxter, Randall (California Department of Fish and Game, Stockton). Personal conversation with author on 19 August 1998.